IFRECOR

INITIATIVE FRANÇAISE
POUR LES RÉCIFS CORALLIENS

THE IMPACT OF CLIMATE CHANGE ON INFRASTRUCTURES IN COASTAL AND INTER-TROPICAL MARINE ZONES

MICHEL PORCHER,
CHRISTIAN BIRAUL, MICHEL ALLENBACH

The impacts of climate change will have an effect on coastal infrastructures and facilities in coral reef environments and related ecosystems in the inter-tropical zone.

This methodology guide's objective is to be a tool to inform and warn different types of potential players on the risks that key coastal infrastructure could incur and the impact that their deterioration could have on coral reefs and related ecosystems. Technical recommendations are provided for the adaptation for each type of infrastructure.

This guide has been written in both French and English.

Les effets du changement climatique auront une incidence sur les ouvrages et les aménagements présents sur les littoraux des zones récifales coralliennes et des écosystèmes associés de l'espace intertropical.

Le présent guide méthodologique a pour vocation de donner à différents niveaux d'acteurs potentiels un outil d'alerte et d'information sur les risques encourus par les principales infrastructures littorales et les impacts que leur dégradation pourrait entrainer sur les récifs coralliens et les écosystèmes associés. Des recommandations techniques sont fournies en matière d'adaptation pour chaque type d'infrastructure.

L'édition du guide est bilingue : français et anglais.

UNC UNIVERSITÉ DE LA NOUVELLE-CALÉDONIE

S2C

MINISTÈRE DES OUTRE-MER

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ITS CONSEQUENCES ON CORAL REEFS AND RELATED ECOSYSTEMS

TECHNICAL RECOMMENDATIONS ON ADAPTATION

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THE IMPACT OF CLIMATE CHANGE ON INFRASTRUCTURES IN COASTAL AND INTER-TROPICAL MARINE ZONES

PREFACE

This year's 21st Conference of Parties to the United Nations Convention Framework on Climate Change, which will take place in Paris in December 2015, is a milestone for negotiating future international agreements on climate that will come into force in 2020, with an objective to keep global warming below 2°C (compared to 2009).

Coral Reef. Photo © Istock.

The Overseas territories already suffer from the first effects of global warming because they are located at all latitudes in four oceans and three continents. Globally, they play an essential role in their capacity to capture carbon, fight against the effects of global warming, sustaining food resources and fighting against poverty in a number of States including island ones, due to the extent of waters under their jurisdiction, the diversity, richness and specificity of their terrestrial and marine biodiversity (mangroves, reefs, ...).

The French initiative for coral reefs and related ecosystems (IFRECOR)1 set down in its 2011¬2015 Action Plan its commitment to focus on change climate:

- in each Overseas territory **an observatory** was put in place **to monitor the impacts of global warming,** relying on scientific protocols and common indicators which were defined with the National Observatory on the impact of climate change (ONERC). They are all now working within a network using a common database run by the University of New Caledonia. This network will eventually be integrated into international networks monitoring climate change;
- an overall assessment has been carried out on **the economic value of services provided** by coral ecosystems (full results will be published in 2016) and it highlighted, in terms of coastal protection against the effects of global warming for example, annual amounts of €66 million in Martinique and from €155 to €220 million in New Caledonia, or for carbon sequestration, €10 million and €8 million per year in Guadeloupe and Martinique respectively;
- **a methodology guide** for local public and private decision-makers and planning developers has finally been drafted, in a pragmatic way, to guide and give them support in the design and development of their coastal planning projects, by taking into account the future impacts of global warming.

As IFRECOR's funders and facilitators, the Ministry of Ecology, Energy and Sustainable Development and the Ministry of Overseas Territories welcome the work done by all the players in IFRECOR's network, which today is reflected in this book's publication: it is intended to clarify, in a concrete and practical way, how local public as well as private players can address the impacts of climate change.

Director General of French Overseas Territories

Alain ROUSSEAU

Director General of Spatial Planning, Housing and Nature Conservation

Paul DELDUC

[1] IFRECOR is a French national action for coral reefs in French Overseas territory communities; it was established in March 1999 on the Prime Minister's decision. It is France's national version of the International Coral Reef Initiative (ICRI). It is under the authority of both the Ministry of Overseas territories and Ecology. Its objective is the protection and sustainable management of coral reefs and related ecosystems (mangroves and seagrass meadows) through innovative and experimental actions in 11 Overseas territories (Guadeloupe, Saint Barthelemy, Saint Martin, Martinique, Reunion, Mayotte, the Eparses Islands, New Caledonia, Wallis and Futuna, French Polynesia and Clipperton).

SUMMARY

Foreseeable climate changes in the 21st century need to be taken into consideration as they are likely to cause major disruptions at the land-sea interface. There is a high risk of either slow deterioration or of the sudden destruction of coastal ecosystems with serious consequences for human activities in coastal areas.

The coral reef ecosystem is one of the most sensitive areas in an inter-tropical zone and as France has Overseas territories in three oceans it is of particular interest The services provided by coral reef ecosystems are increasingly recognized today and their protection is a vital issue for all inter-tropical local authorities. This is the reason why IFRECOR was founded.

Rising sea level, the increasing occurrence of extreme weather conditions, increasing air and water temperatures and acidification of the oceans will all have a major impact on coral formations and their marine ecosystems including a direct effect on the biology of the most sensitive species. They will also have an indirect impact on both individual structures and collective infrastructure located along the coast. Some structures risk deterioration and pollutants will increase in coral reefs and in their marine ecosystems). To help identify appropriate adaptation strategies when planning future developments in coastal areas, the possible impacts of climate change on each type of coastal zone development need to be analyzed and the likely effects on sensitive marine areas close to the coastline need to be calculated.

Such an analysis will:

- identify potential risks to specific infrastructures and the technical measures that need to be taken to protect existing infrastructures, maintain their function and optimize future developments;
- if the right measures are taken, the impact of any damage on sensitive natural environments can be reduced and the environmental resilience to the effects of climate change enhanced.

This methodological guide is designed to inform different actors of the risks faced by the main coastal infrastructure and of the impact that deteriorating infrastructure could have on the coral ecosystem. We do not claim to be exhaustive or to answer all possible questions.

The guide contains:

- a state-of-the-art review of climate change and its consequences for the land-sea interface (GIEC 2014) in French Overseas territories in inter-tropical zones;
- an analysis of the main infrastructure offshore and infrastructure directly linked to activities along the coast whose deterioration could have an impact on coral reef environments and related ecosystems.

For each type of infrastructure, the guide provides:

- an intentionally simplified description of the structures and of the impacts they may have on the natural environment;
- an inventory of structures in each French overseas territory and overseas collectivity;
- a description of possible impacts of climate change on infrastructure and their implications for coral reef environments and their marine ecosystems;
- technical recommendations on how to adapt existing infrastructure to climate change or on the construction of new infrastructure.

As most of the infrastructure is directly affected by water, including its management and the structures built to protect it against the impact of floods and flooding, a chapter is dedicated to these aspects.
In the conclusion, we present a matrix table containing our recommendations for structures that may be the most affected by these hazards.

This summary underlines the high risk of damage to existing infrastructure and the consequences for coral reef environments and related marine ecosystems. It is crucial to implement the necessary measures to limit such risks as rapidly as possible. Other tables are included in this guide to help decision making, they are based on diagnoses of exisiting infrastructure and list the alterations we recommend to adapt to climate change (for example items to be incorporated in a diagnostic survey).

Technical investigations conducted in a French overseas territory will enable the development of a strategy and subsequently preparation oif a Climate Change Adaptation Plan for specific infrastructures, based on the following measures:

- defining priority actions;
- prioritising actions and estimating construction costs;
- drawing up a schedule for implementation;
- Setting up a local group to monitor the action plan and the technical and scientific aspects, in collaboration with the appropriate central technical departments, especially monitoring climate evolution parameters and analysing feedback from extreme weather conditions).

At the same time, it is important to:

- check that the effects of climate change have been taken into account in existing plans and development plans concerning structures in each territory;
- conduct awareness raising campaigns with local populations on the possible impacts of climate change;
- reinforce climate change observatories to optimise adaptation based on ongoing climate change;
- create a policy to ensure climate risks are taken into account, using a project quality approach. These risks must be included in Schemes Organizing Quality Assurance Plans (SOPAC), and subsequently in QAPs (Quality Assurance Plans).

Turtles in Kelonia on Reunion Island
Photo: © I, Thierry Caro via Wikimedia Commons

CONTENTS

NB: Chapters 2, 3 and 4 each have subchapter linked to a type of structure, these include:
1. Overview of structures
2. The different types of structures in Overseas territories
3. Possible impacts of climate change
4. Technical recommendations on adaptation

Coral reef fish © Mateusz Dutkiewicz

INTRODUCTION

IFRECOR: the French Initiative for Coral Reefs was created in 1999; its objective is to ensure sustainable protection and management of coral reefs and related ecosystems (mangroves, seagrass meadows) in French overseas territoryies. IFRECOR is made up of a national panel and a network of eight local committees representing French territories with coral reefs: Guadeloupe, Martinique, Reunion Island, Mayotte, Eparses islands, New Caledonia, Wallis and Futuna and French Polynesia.

It is widely accepted by the international scientific community that any degradation of coral environments and related ecosystems will directly increase the vulnerability of the territories considered in this guide *(see table page 15)*.

Coastal infrastructures will all be affected by evolving climate change parameters. It is thus appropriate to review these structures and facilities, whether they are located close to coral reefs or in related watersheds because the damage they will undergo is likely to augment the negative impacts of climate change on coral reefs and related ecosystems.

This guide begins with a review of current knowledge on climate and climate change (i.e. an update on the basic elements available to predict future climate and a description of extreme weather conditions in inter-tropical zones) in addition to the review of existing infrastructure in coastal areas.

- Water-related infrastructure and structures:
  - stormwater;
  - wastewater;
  - water consumption and drinking water supply systems.
- Coastal protection structures.
- Key public infrastructure:
  - airport infrastructure;
  - port infrastructure;
  - road infrastructure;
  - Energy-related infrastructure.
- Infrastructure linked to coastal activities:
  - tourist infrastructure;
  - industrial and artisanal infrastructure;
  - housing and urbanisation;
  - fisheries, aquaculture and pearl oyster farming;
  - agriculture and forestry.

A description of each type of infrastructure is provided. An inventory of exisiting infrastructure in French overseas territories was carried out and the possible impacts of climate change on these infrastructures identified.

Finally, technical recommendations are provided for the adaptation of existing infrastructure and/or how to construct new infrastructure.

This guide is intended as an aid to reflection by the decision¬ makers and engineers who need to address coastal infrastructure management issues in view of climate change and preserve coral reefs and related ecosystems.

However, it is not intended to be a technical manual, although it includes a number of technical aspects. It is up to each decision maker, public project manager (or private manager) to contact the appropriate authorities and technicians before forming a final opinion on the specific issues linked to their project.

The guide is desiged as an educational tool to highlight specific areas where problems involving coastal facilities in major communities in French overseas territories could arise or exisiting problems could escalate **due to increased climate forcing.**

Awareness raising has different objectives:

- **reinforcing the role and the importance of climate change adaptation strategies, schemes and national plans in French overseas territories, to limit possible malfunctions and impacts on the coral reef ecosystems as far as possible;**
- **drawing the attention of local decision-makers to the importance of the potential impact of climate change on coastal areas and providing them with the necessary decision-making tools.**

It is vital that the technical recommendations are in line with progress, made in climate change scenarios, but also with technical and scientific advances concerning both the appropriate infrastructure and natural environments. This is a difficult approach, but was chosen to help avoid burdensome and constraining proposals which would be difficult to adapt in the future, if required.

The guide contains:

- an updated review of climate change and its consequences for the land-sea interface (GIEC 2014), with a focus on the inter-tropical zones in French overseas territories;
- an analysis of both major offshore infrastructure and infrastructure directly linked to coastal activities whose deterioration could have an impact on coral reef environments and related ecosystems.

For each type of infrastructure, the guide provides:

- an intentionally simplified description of the structures and their impact on the natural environment;
- an inventory of local structures in each French overseas territory;
- a description of possible impacts of climate change on these infrastructures and their implications for coral reef environments and related ecosystems;
- general technical recommendations on how to adapt existing infrastructure or how to construct new infrastructure.

As most of the infrastructure described is directly affected by water, including its management and structures built to protect it against the impact of flooding, a dedicated chapter deals with these aspects.

The conclusion includes a matrix table listing the types of structures which could be the most affected by the hazards .and a summary of appropriate recommendations. Tables listing the components of infrastructure diagnoses are included to help decision makers (for example items to be incorporated in a survey), along with alterations recommended to adapt to climate change.

Finally, an appendix is provided for each chapter suggesting where the reader can obtain further information.

CORAL REEFS AND RELATED ECOSYSTEMS

CORAL FORMATIONS

Coral (biological characteristics)

Corals are marine invertebrate animals belonging to the cnidarians genus (like sea anemones and jellyfish). Coral has a polyp body form with a mouth, a stomach, a wall and stinging tentacles to catch food. Polyps which live alone are called a solitary coral. But most corals are made up of colonies of hundreds of genetically identical polyps, all stemming from the division of a single polyp. Polyps capture zooplankton as food using their stinging cells.

Photo: Coral reef ® Wallis and Futuna's Environmental Territorial Service

Photo: Polype ® Parent Gery

Coral lives in symbiosis with algae: some types of corals have their own symbiotic micro-algae in their tissues called zooxanthellae.

These photosynthetic algae capture light thereby bringing an additional energy source to the coral which enables it to grow its calcareous skeleton. In turn, the coral provides a stable environment and the elements the algae needs to complete the photosynthesis process.

Global warming is a major threat to coral reefs. In particular, rising water temperatures threaten the fragile balance between polyps and zooxanthellae, which causes a coral bleaching phenomenon.

Formation of coral reefs

A distinction is generally made between soft corals (such as alcyonacea) and hard corals called «reef-builders». Unlike soft corals, hard coral polyps secrete a solid limestone skeleton, which is the foundation of a coral reef. After the organism dies, the organic part decomposes while the mineral skeleton lives on. Over the years, the lime scale residues build up and corals continue to grow on the surface of this structure, and this is how a coral reef is formed. Volcanic islands in inter-tropical areas provide an ideal substrate for polyp larvae and hence for the formation of coral reefs.

THE DIFFERENT TYPES OF REEFS

Three main types of coral reefs can be found in French overseas territories.

• A fringing reef

Fringing reefs form a border along the shoreline and have a shallow backreef zone, they are mainly found in Reunion Island and in the Caribbean.

• A barrier reef

Unlike the fringing reef, the barrier reef is separated from the coast by a lagoon. Barrier reefs are found in New Caledonia, around the islands in French Polynesia, on Wallis and Mayotte. There is also a barrier reef on the east coast of Martinique and Guadeloupe (Grand Cul-de-sac Marino). A sub-variety is made up of double barrier reefs, consisting of two parallel barrier reefs. New Caledonia and Mayotte each have double coral barriers, which are extremely rare (there are fewer than 10 in the world).

Bora Bora's reef complex. © Überraschungsbilder

• An Atoll

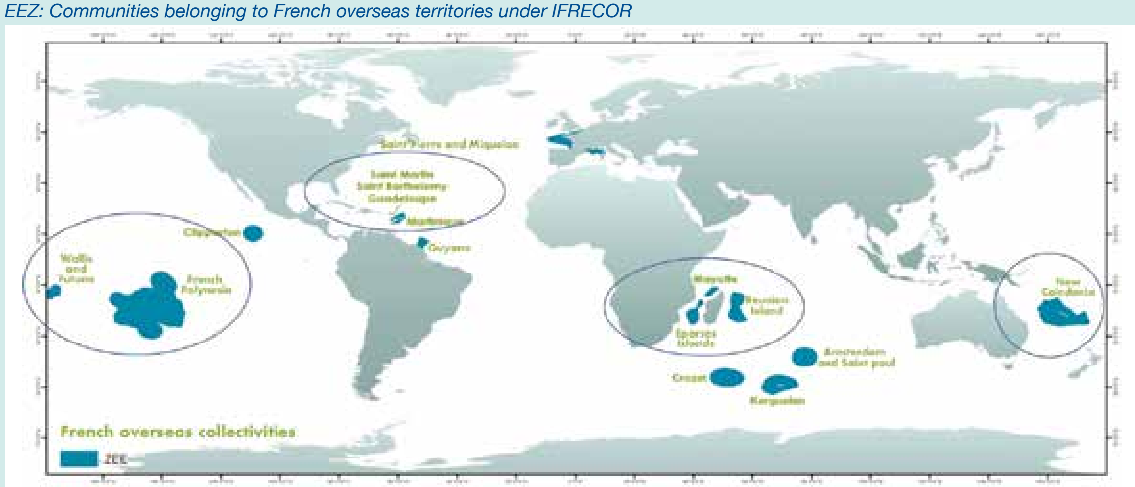
An atoll is an offshore coral reef. It is ring-shaped and encircles a sizeable lagoon of variable depth. The reef can be continuous and ring-shaped or a set of islands separated by channels connecting the lagoon to the ocean. French Polynesia has atolls. Clipperton and Europa and Bassas da India Islands (Eparses Islands) are atolls. Reef benches exist in addition to this geomorphologic trilogy. Reef benches are coral formations on shallow offshore beds.

Coral reefs, like tropical forests, are among the richest and most productive ecosystems in the world. They host exceptional biodiversity and provide an unparalleled panorama of underwater life including corals, fish, rays, turtles and sharks. A third of all known marine species, (nearly 100,000 species) live in reefs.

SOME EXCEPTIONAL FEATURES OF FRENCH OVERSEAS TERRITORIES

- France is the only country with coral reefs in three oceans. These different contexts explain their exceptional diversity.
- These coral reefs and lagoons cover approximately 55,000 km2 which is almost 10% of the total surface area of coral reefs in the world.
- 20% of the world's coral atolls are located in French Polynesia.
- New Caledonia's barrier reef is the second largest in the world (1,600 km long).
- New Caledonia and Mayotte both have double barrier reefs, an extremely rare phenomenon in the world (there are fewer than 10).
- France has one of the largest Exclusive Economic Zones in the world, largely due to the presence of these reefs; French overseas territories account for over 90% of the French maritime area.

EEZ: Communities belonging to French overseas territories under IFRECOR



RELATED ECOSYSTEMS: MANGROVES AND SEAGRASS MEADOWS

Mangroves and seagrass meadows are ecosystems «associated» with coral reefs. Mangroves are located along the shoreline.

MANGROVES

Mangrove, Martinique. Photo: © Ifrecor.com

Mangroves are aquatic «forests» lying between fresh water and seawater. This ecosystem is specific to an intertidal zone and is one of the most productive in the world. It has developed the capacity to adapt to highly selective conditions and its different plant species depend on specific parameters including salinity (Walsh, the 197 flooding duration (McKee, 1993), the sedimentation rate (Ellison, 1998). Currently, mangroves occupy about 75% of tropical shorelines and cover 200,000 km2. Their vegetation is made up of ± 19 mangrove families, broken down into ± 27 genuses ± 70 species (Marchand et al. 2010). A mangrove is crucial from both an ecological and economic point of view. It plays a vital role in the conservation of tropical coastlines. It stabilises the shoreline, and acts as a barrier against erosion caused by swell by reducing wave energy and changing the hydrodynamic conditions. In addition, due to its high productivity, it is the beginning of the nutrient cycle in coastal zones. The coastal waters around mangroves are generally rich in shrimps and fish. A mangrove is an important shelter, and hosts significant animal biodiversity including molluscs, crabs, fish, lizards, snakes, turtles, and birds.

SEAGRASS MEADOWS

Seagrass meadows. Photo: © Alain Pibot

These beds of seasgrass form marine «meadows». They include many different underwater plant species. Located between the reef and a mangrove, they are also home to a wide range of fauna and flora including sea urchins, sea cucumbers, and starfish. They are also nurseries offering shelter and food for many juvenile reef fish,. Marine herbivores including the dugong or manatee adore these marine meadows.

Coral reefs, mangroves and seagrass meadows are all closely interacting ecosystems. They are the source of many ecological services but are particularly fragile and currently threatened by climate change.

SERVICES PROVIDED BY CORAL REEFS AND RELATED ECOSYSTEMS

When coral reefs, mangroves and seagrass meadows are healthy they provide human communities with:

- a supply of food: an estimated half a billion people live off reefs;

- innovative development: a large number of activities related to fishing, aquaculture, pearl oyster farming, for jewellery or even medicinal purposes are possible in coral zones. Mangroves and seagrass meadows provide many fishing resources, and mangroves also provide wood;
- tourism: coral reefs are a source of beauty and wonder; they are an icon in French overseas territories;
- coastal protection: reefs, mangroves and seagrass meadows protect the coast from erosion by reducing swell. For example, a coral reef can absorb up to 97% of a wave's energy, and 200 meters of mangrove along the shoreline can absorb 75% of its energy, thus protecting the coastline and coastal infrastructure;
- finally, mangroves and seagrass meadows trap the finest sediments, thus protecting coral reefs from asphyxiation due to hyper-sedimentation.

Worldwide, nearly 500 million people depend on coral reefs for sustenance, coastal protection, renewable resources and tourism. And around 30 million people, among the world's poorest, depend entirely on coral reefs for their food. It is estimated that the goods and services provided by coral represent an annual net profit of 30 billion US dollars to the world's economy (César, 2003). In monetary terms, revenues from fisheries located near mangroves are estimated at US$10,000/ha/year, although this varies coinsiderably depending on the area and market value. The total value of goods and services provided by mangroves exceeds US$ 200,000/ha/year in some cases (Marchand, 2010).

However, degraded coral reefs may reduce fish catches which can result in food insecurity due to protein deficiency; a reduction in revenues from tourism and an increase in the risk of erosion and coastal destruction caused by natural disasters.

It is thus essential to preserve these unique ecosystems for current and future generations.

Pocillopora corals. Mayotte. Photo: © Jean-Pascal Quod

Aerial view of Sainte Anne. Photo: © Franck Mazéas

Taemae Lagoon, Moorea, French Polynesia. Photo: © Franck Mazéas

CHAPTER 1

1 / CLIMATE AND CLIMATE CHANGE A STATUS REPORT

Parameters to take into account for coastal infrastructure. We refer here to the 5th IPCC report (2013-2014).

NEW SCENARIOS USED BY THE IPCC

The IPCC (Intergovernmental Panel on Climate Change) is now using new baseline scenarios (RCP scenarios) rather than the previous SRES scenarios (see below). In the following paragraphs we refer to the ONERC paper «Discovering new RCP scenarios and SSP used by the IPCC (French Ministry of Ecology, Energy and Sustainable Development - 2013- Authors: Sylvain Mondon and Maurice Imbert).

The SRES scenarios in the «Special Report on Emissions Scenarios» were defined by the IPCC in the late 1990s and used up until 2007. The report discusses a collection of possible future scenarios for companies which incorporate multiple economic, technological and social determining factors). In preparation for the 5th IPCC Assessment Report, a group of international experts identified four scenarios to be used as references, which are representative of changes in concentrations (RCP - Representative Concentration Pathways) of greenhouse gas (GHG), ozone and aerosol precursors for the 21st century and beyond. These scenarios can be correlated with quite important global efforts to reduce GHG emissions.

Weather conditions and associated impacts of climate change were deduced by climatologists for each of the four «representative pathways». Sociologists and economists also worked on scenarios with differing socio-economic development characteristics and adaptation and alleviation strategies. A group of five scenarios named SSP (Shared for Socioeconomic Pathways) was defined.

This approach allows everyone to collaborate and ensures coherence between climatologists and economists.

Photo: © Michel Porcher

The profiles of RCP: Representative Concentration Pathways are referent scenarios for changes in radiative forcing over the 2006-2300 timeframe.

Name	Radiative forcing	GHG Concentration (ppm)	Pathway
RCP 8,5	> 8.5 Wm2 in 2100	> 1.370 eq-CO2 in 2.100	Increasing
RCP 6,0	-6 Wm2 at stabilization level after 2100	-850 eq-CO2 at stabilization level after 2100	Stabilizing without exceeding
RCP 4,5	-4.5 Wm2 at stabilization level after 2100	-660 eq-CO2 at stabilization level after 2100	Stabilizing without exceeding
RCP 2,6	Peaking at -3 Wm2 before 2.100 then declining	Peaking at -490 eq-CO2 before 2.100 then declining	Peaking then declining

Table 1: Main characteristics of Representative Concentration Pathways (Moss et al Nature 2010)

Radiative forcing, expressed in W/m2, is the change in radiative results (declining radiation minus increasing radiation) at the top of the troposphere (10 to 16 km in altitude) due to a change in climate patterns such as the concentration of greenhouse gas emissions. The 2011 value is 2.84 W/m2.

Regions	Average temperature in °C	Rainfall %
Caribbean	+2°C (+1.8 to +2.4°)	-12% (-19 to -3%)
Guyana	+3.3°C (+2.6 to +3.7°)	+0% (-3 to +6%)
Indian Ocean	+2.1°C (+1.9 to +2.4°)	+4% (+3 to +5%)
South Pacific	+1.8°C (+1.7 to +2°)	+3% (+3 to +6%)
New Caledonia	+1.9°C (+1.8 to +2.1°)	-6,5% (-5 to -8%)

Table 2: Predicted temperature and rainfall between now and 2099. Scenario A1B - IPCC 2007. The unpredictable ranges (quartiles 25/75%) are in brackets (Extracted from: Petit J and Prudent G. 2008, Climate Change and biodiversity in the EU Overseas territories. IUCN, Brussels. 196 pp).

1.1. CORE ELEMENTS FOR CLIMATE FORECASTING

Forecasts for climate change take the following major parameters into account:

- rising temperatures,
- changes in rainfall,
- intensification of cyclones,
- melting ice,
- rising sea levels.

Meteo-France is now running regional simulations in French overseas territories to supplement current information. The simulations can be viewed on the «Drias the future climate» portal. The regional values given below are taken from this portal: www.drias-climat.fr

Temperature and rainfall: the global average increase in temperature by the end of the century will be+ 2.8 °C.

A significant rise in temperatures is expected in the French overseas territories, but with differences depending on the geographical area. A significant increase in rainfall is also expected in the higher latitudes (more than 10% in the Arctic and Antarctic), but the values vary from one region to another and are lower in subtropical regions *(see Table 2)*.

The 5th IPCC report confirms the most pessimistic temperature predictions, i.e. the increase in global average temperatures could be between +2.6°C and 4.8°C (the RCP 8.5 scenario being the worst).

• Intensification of cyclones

According to IPCC forecasts, cyclones are expected to intensify in all tropical zones, with stronger maximum winds and higher occasional rainfall. This intensification is linked to rising tropical sea temperatures; however, it is not yet possible to identify changes in cyclone frequency.

• Melting ice

One of the best indicators of the impact of global warming is the extent of the ice shelf surrounding Greenland: from 1978 to 2007, the ice cover

A SUMMARY OF CLIMATE CHANGE IN FRENCH OVERSEAS TERRITORIES

TEMPERATURES AND RAINFALL

This section provides an initial estimate of temperature and rainfall forecasts for French overseas territories (French West Indies, French Polynesia, Reunion Island and New Caledonia). The results found using the regional climate model Aladin-Climat, state that every region can expect:

- a 0.7 °C increase in temperature by 2100 in the RCP2.6 scenario and a 3-3.5°C increase in the RCP 8.5 scenario;
- a decline in average rainfall, especially in the dry season.

CYCLONE ACTIVITY

We refer here to the latest IPCC report:

- at the beginning of the 21st century: a slight change in the frequency of tropical cyclones was predicted. Only a few studies showed an increase in the intensity of cyclones in the North Atlantic basin and an increase in the frequency of Category 4 and 5 cyclones in the North Atlantic and Pacific Southwest basins.
- by the end of the century: it is likely that the frequency of tropical cyclones worldwide will decline or stay the same. Yet the average rainfall and maximum average wind speed of tropical cyclones will undoubtedly increase.

Extract from «France's climate during the 21st century» Volume 4. Regional scenario - 2014 edition-for France and its Overseas territories -August 2014 - G. Ouzeau et al.

decreased by 40%. Between 2005 and 2007, more than one million km2, an area equal to five times that of the United Kingdom, was lost. These results exceed all forecasts in the IPCC (2007) assessment report. In addition, mountain glaciers have retreated and snow cover has declined in both hemispheres, except in the Antarctic, where the ice cover currently appears to be increasing.

• Rising sea levels

A global rise in sea levels has been observed for several years and directly linked to the global warming phenomenon. It is mainly due to the thermal expansion of the oceans as they become warmer, but also because glaciers and ice sheets are melting. **The global sea level has risen by 0.20 meters since 1900 and now appears to be accelerating.** The 5th IPCC report (RCP 8.5 – being the worst scenario) forecast **an average increase of 0.45 to 0.82 m**. In 2100, the maximum increase could be between 0.52 and 0.98 m with a rate of 8 to 16 mm/per year from 2081 to 2100. **These estimates have increased significantly since the previous IPCC report (AR4, 2007) whose highest forecast was 0.59 m.**

A similar increase is expected in most French overseas territories, but to varying degrees depending on the region concerned.

Other climate change parameters, such as oceanic acidification, have not been mentioned as they are not expected to have a real impact on coastal and marine structures and infrastructure. However, acidification will have a major impact on the growth and survival of coral, and could eventually have a significant indirect effect on airport infrastructure located on or near reefs, as coral formations provide natural coastal protection against erosion (a large reef can absorb up to 90% of a wave's impact). **So the destructive effect of strong swells on infrastructure could be magnified.**

Collapsed beach seawall in Saint Paul, Reunion Island 2012. Photo: © BRGM

1.2. EXTREME WEATHER PHENOMENA IN INTER-TROPICAL ZONES

Most of the information in this section comes from Meteo-France publications. The largest coral reefs are found in inter-tropical zones where the climate enables them to develop, **but includes periods of severe weather.** These events are usually tropical depressions of varying strength with strong winds and heavy rainfall: tropical depressions (TD), heavy tropical depressions (HTD), cyclones, typhoons, and hurricanes.
Statistics include data on rainfall, wave height, wind speed, minimum, average, and maximum temperatures, based on recorded weather reports.

These statistics give the probability of a return period, which can be annual, decadal, 50 years or a century; however, these are only statistics and a ten-year return for example, may occur twice in this specific period, i.e. in a shorter time frame than that defined, and even only 8 days apart!

SUMMARY OF CYCLONES AND TROPICAL DEPRESSIONS

Tropical depressions usually originate in the temperature of sea water, which is a huge potential source of energy (usually from 26 °C at the starting point at a depth of 50 meters in the ocean mass).
It is however very difficult, if not impossible to predict the statistical probability of a depression occurring at a given location or its level of violence; only the inter-tropical confluence can forecast a non-quantifiable risk. Cyclone analysis involves counting the occurrence of cyclones in a large defined geographical area along with their power.

The actual zone seriously affected by a depression at a given time is small, but the path a depression takes is variable and can only be predicted at most a few hours in advance.

The risk of being hit by a HTD or cyclone, especially for small islands in a vast ocean environment, is thus the combination of a risk of a depression starting and that its path crosses a particular island, which fortunately means a significantly low probability of high impact.

A cyclone is a vast area where the atmospheric air rotates around a low pressure centre, called a trough: the depression is the eye of the cyclone. The pressure gradient between the zones of surrounding high pressure and low pressure causes air to be drawn into the centre, the Coriolis acceleration deflects winds to the right in the northern hemisphere and to the left in the southern i.e. anti-clockwise in the northern hemisphere and clockwise in the southern. There are consequently no cyclones near the equator between latitudes 7° north and south, where acceleration is zero or too weak. The trough will thus follow the points where the temperature of the seawater is at its highest and release maximum energy due to the latent heat of seawater condensation. This energy raises the thermal temperature from 10 °C to 25 °C. The intensity of a cyclone is determined by the maximum wind speed it generates, which is an easy parameter to predict and measure. The destruction caused by a cyclone is actually caused by the wind (the most violent wind ever recorded scientifically was 408 km/hr on April 10 1996, on Barrow Island in Australia).

The evaporation of large quantities of hot water releases high thermal energy, which is transformed into very high winds and extensive, powerful clouds.

Tropical cyclones plague the inter-tropical zone, where coral reefs are located, but extra-tropical and even polar cyclones occur.

Cyclone Bejisa, January 2014. Leaching on roadways, dispersal of pollutants and soil deposits. Photo © Imazpress

THE EFFECTS OF CYCLONES AND TROPICAL DEPRESSIONS

Effects due to high winds

Cyclones often cause irreparable damage. They destroy electricity networks, precarious dwellings, and the vegetation. For example, a Category 4 cyclone is accompanied by sustained winds of 220 to 240 km/hr; some gusts exceed 280 or 300 km/hr. If the pressure at sea level is as low as 920 millibars, it is a class 5 cyclone (the lowest pressure ever recorded at sea level was Typhoon Tip in the Pacific Ocean with 870 millibars measured on the 12th of October 1979 with a maximum wind speed estimated at about 310 km/hr!). A cyclone's magnitude is the pressure on a surface area proportional to the square of the wind speed. A 200 km/hr wind is four times stronger than a 100 km/hr wind. Buildings that meet cyclone standards can withstand winds of 240 km/hr (class 4). This wind speed corresponds to a dynamic pressure of 310 kg force/m2.

Effects due to rain

Heavy rains are also destructive, and more importantly, they are the biggest killers, especially since they may accompany less intense cyclones; **the most extensive damage, the most destruction, and large numbers of victims are mainly due to the effects of water and rainfall,** i.e. rapidly flowing gullies, overflowing rivers, raging mountain torrents, cut off and dangerous roads, landslides and mudslides, and the destruction of homes located next to bodies of water.

The amount of rainfall generated by a cyclone varies considerably. High intensity cyclones can be quite «dry», with only a few dozen milimetres of water recorded in their path; others, considered to be less intense because the winds are moderate, cause flooding and deadly landslides. Local conditions can play an important role in the impact of rainfall:

- **mountainous terrain** magnifies vertical movement and hence the instability of the terrain and the condensation of evaporating water;
- the presence of a mountain chain or other natural obstacle **can change the direction of the system;**
- **when a cyclone moves slowly,** the amounts of rain increase, which happens when it remains stationary in one place.

The effects due to the storm surge and the state of the sea:

The storm surge causes a rush of seawater, a rise in sea level that floods everything in its path, and destroys everything along the coastline. The surge is caused by high winds blowing over the surface of the sea around the eye of the cyclone, which tend to create a strong current through friction, and is generally offset at depths of over 50 to 60 m, by a counterflow in the opposite direction.

When a cyclone reaches the continental shelf or is close to land, the counter current disappears, and only the surface current remains strong. This produces a natural surge of water towards the surface, which builds up as it approaches the shore. The steeper the shelf, the greater the build up.

Depressions tend to push the water level up (intumescent or inverted barometer effect). The normal atmospheric pressure is approximately 1 bar at sea level, which is the pressure exerted by a 10 m water column, one millibar is equivalent to 1 cm of water.

The «overvalue» reaches maximum when all the effects are combined with a high tide. In the southern hemisphere, this is the case of cyclones moving westward in the north¬eastern part of the eye. This «spike» is sometimes referred to as the storm surge, which usually lasts around ten minutes and maximum two hours. In areas where there is a large continental shelf, i.e. the sea remains shallow for kilometres offshore, **intense cyclones can cause storm surges of 5, 6, or even 7 meters;** so under certain local conditions (e.g. Bangladesh) victims can number in the hundreds or even thousands of people, their homes devastated and washed away.

«Bagging» can occur in lagoons, which is when water is unable to evacuate as quickly as it enters.

Waves can be huge, sometimes exceeding the theoretical wave height limit of 15 meters. The energy generated by cyclones is usually very intense and causes huge rollers on exposed shores and up to several hundred kilometres from the weather system.

Erosion on a beach in Reunion Island. Photo: Michel Allenbach

French Polynesia, Fakarava. Photo: © Franck Mazéas

CHAPTER 2

2/ WATER-RELATED INFRASTRUCTURES AND STRUCTURES

This chapter deals with all water management structures that could have an impact on the coastal and marine environment, in particular coral reefs and related ecosystems, stormwater, wastewater, drinking water systems and coastal protection structures.

The water cycle is an integral part of life and of human activities; it begins and ends in the ocean. Both natural phenomena and repercussions from human activities and structures linked to water can have a strong impact on coral reefs and related ecosystems.

Any structure linked to the management of stormwater and wastewater is very sensitive to climate. The main risks are:

- risks associated with civil protection as rainfall is often destructive. Rainfall is the deadliest of all weather hazards leading to rapidly overflowing ravines, flooding rivers, roads may become dangerous and even cut off, landslides and mudslides, destruction of homes located near water;
- health risks: heavy rains frequently pollute stormwater systems creating risks for swimmers and for the consumption of living organisms caught in polluted rivers or the sea;
- risk of degradation caused by hyper-sedimentation and/or the pollution of sensitive natural environments, leaching and erosion of the soil during heavy rainfall resulting in floods and overflowing water management structures (water retention structures, water treatment plants (lagooning and sewage treatment plants);
- risks of deterioration of buildings due to heavy rains, especially during the cyclone season.

Coastal protection structures are included in this chapter because they are directly linked to water and are affected by erosion and coastal degradation.

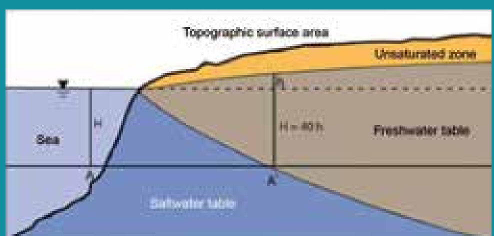
SALTWATER INTRUSIONS

«Saltwater intrusion» occurs in coastal freshwater aquifers in natural coastal environments. This is where bodies of saltwater and freshwater meet and form a hydrologic barrie, also called a «corner» or «front». It is a freshwater/saltwater interface, and is made of brackish water.

As saltwater is heavier (its density ranges between 1.023 and 1.034) and thicker than freshwater, they only interact when there is a movement between the two water bodies. Given this difference in density, the freshwater table must be 30 to 40 m deep to exert sufficient pressure to contain the saltwater in a sustainable way.

In the coastal areas of islands, the freshwater table is in direct contact with the denser saltwater table. If too much groundwater is pumped and/or the level of the watertabl drops due to a low rainfall period, the saltwater «pollutes», the freshwater aquifer used as a source of water for irrigation, drinking water, and water for industrial use, leading to a shift in the saltwater/freshwater interface.

A salt intrusion rises very slowly towards land and is difficult to reverse because saltwater acts as a «impermeable barrier». Once the intrusion has risen, the hydraulic gradient required to move it back is greater than the original one.



A schematic section perpendicular to the coastline according to Ghyben Herzberg (extracted from Frissant et al. 2005)

An example in Guyana: *http://www.dailymotion.com/video/xatrmq_crise-du-bevel-sale-en-guyane_news*

An example in New Caledonia: *http://www.geophysical.nc/carte/poum-biseau-sale*

2.1. STORMWATER

In a natural environment, rain and stormwater infiltrates the ground to the limit of its permeability thereby supplying the water table. Some water evaporates and some is captured by the vegetation. Any excess runs off and supplies surface water bodies: streams, rivers and lakes.

Weather records from **specific locations are used to measure the probable cumulative rainfall (generally on a monthly and annual basis) and the maximum recurring rainfall (usually on an annual, decadal, fifty year or centennial and exceptional time frame).** It is important to note that, in statistical terms, the same measurement may be recorded several times within a specific period or only recur after the period has ended.

Groundwater is naturally present in different kinds of water tables that account for part of the surface water flow between periods of rainfall. These can be open or retained water bodies, superficial or deep water, and sometimes lenticular on islands, especially coral islands where the freshwater floats on top of the saltwater.

2.1.1. SUMMARY OF INFRASTRUCTURE AND STRUCTURES LINKED TO STORMWATER MANAGEMENT

OVERVIEW

Outside natural environments, human settlements and human activities have required the construction of artificial structures to collect and conserve water, or to allow it to circulate or evacuate through an outlet. These include:

- water holes: the oldest and simplest structures were naturally occurring holes or holes dug by hand to access open or very shallow water. These have gradually become more sophisticated;
- canals built to capture some of the flow in waterways to direct it into a channel or pipe;
- reservoirs: in the absence of natural lakes, it is often necessary to build dams to capture large quantities of water not only to meet water requirements, but also to regulate the flow of water downstream by withdrawing all or part of the flow;
- flood or storm weirs: these weirs are built where it is impossible to capture the overflow and/or excess water. An overflow in a water retention structure can destroy it, unlike canals, which can be submersed without being destroyed;
- water channels and/or dykes: waterways have been channelled, altered, or contained by earth mounds or walls to improve the flow of some rivers and keep them in their «normal» beds. These structures may improve or enable navigation in inland waterways;
- crossings and bridges: structures have been built to cross waterways, which were formerly crossed by fords: viaducts for motorways, roads and railways, but also aqueducts for some ancient water supply channels or even canals that bridge the waterway;
- stormwater drainage pipes: rain water is collected and channelled by pipes to different outlets, especially in urban areas;
- desludging and/or water retention tanks: in addition to the above-mentioned structures, it is often important to build water retention structures to control the flow to the downstream network that serves as an outlet. These structures are often built to desludge i.e., to limit sedimentation in waterways, and to retain certain accidental effluents before they are discharged into the natural environment;
- anti-salt dams help maintain a certain level of freshwater above a salt intrusion;
- The size of these structures has varied over time, originally they were large and their dimensions were calculated according to resources available at the time of construction, then by the water flow rates, and the acceptable recurring flow rate, but also to function of the structure: food, protection, regulation, and particularly the funding capacity.

THE IMPACTS OF STORMWATER MANAGEMENT STRUCTURES ON THE NATURAL ENVIRONMENT

These structures have both positive and negative impacts:

- **Positive impacts,** linked to the objective of building the structure (controlling flooding and desludging phenomena) to limit the transport of terrigenous particles and sometimes to prevent pollutants dispersing in the natural environment.
- **Negative impacts:** changes to a biological cut-off effect, degradation caused by flooding during extreme weather conditions (turbidity, hyper-sedimentation and sometimes pollutants trapped in desludging tanks, erosion). When a structure is destroyed it can cause major damage to the downstream environment, both to assets and possibly to people. These impacts are often linked to under-sized water retention infrastructure and insufficient riverbank protection against erosion and sometimes lack of maintenance of the facilities (dilapidated and infrequent cleaning of desludging tanks or ditches and canals) and river banks (jammed up, full of rubble, sediments and waste).

2.1.2. INFRASTRUCTURE LINKED TO STORMWATER MANAGEMENT IN FRENCH OVERSEAS TERRITORIES

Equipment in French overseas territories generally complies with global standards, and the design of the structure takes into account the tropical rainfall conditions and the lie of the land (many sites have geological formations that are easily submerged by stormwater). Specific alterations may be required, but these are sometimes difficult to implement, especially given the risk of cyclones which requires oversizing of certain structures: ditches, bridges, flood spillways on dams.

However, the population density varies considerably with the territory, requiring the use of equipment that is sometimes atypical. For example, in Tahiti, gratings were put on retention structures in rivers running through inhabited valleys to retain different types of waste, thereby protecting the lagoon, beaches and coral reefs downstream.

Scientific observation facilities (experimental measurement sites) have been set up to measure the flow of solids and liquids in waterways. For example French Polynesia and New Caledonia, both of which have several mining catchment areas, have been monitored over the last five years to check the level of fine sediment deposits in the lagoon, and ultimately, to protect the coral reefs.

(DOM)
IN FRENCH OVERSEAS TERRITORIES

In general, stormwater management structures are basic and although in theory, sewage networks exist in the overseas territories, in practice, problems of non¬compliance are ubiquitous. The many stormwater connections to wastewater networks dramatically increase the amount of polluted water in waste water treatments plants (WWTPs). And in most cases, once this polluted water is in the WWTP there is no way of confining it. As a result, substantial leaching occurs during the rainy season and overloaded WWTPs often release waste water directly into the natural environment.

Finally, there is very little or even no treatment of stormwater, which flows directly into the sea, thus strongly contributing to the pollution of the marine environment.
Thus, despite the efforts already made, a lot of work remains to be done and improved stormwater management programmes are planned. The aim is to reduce the risk of flooding and to optimise the management of terrigenous deposits and associated pollutants to limit their impact on the sensitive marine environment. One of the major problems to be resolved is the rehabilitation of sewage systems and to prevent stormwater overflow from entering wastewater systems.

(COM)
IN FRENCH OVERSEAS TERRITORY

IN FRENCH POLYNESIA

In Papeete, a stormwater system exists, but there is still a risk of floods in low-lying regions. During heavy rains, the network collects heavy loads of suspended solids (SS) resulting from erosion in the watershed and the many excavation works on slopes. In additiion, macro-waste clutters the highly urbanised valley bottoms (in particular, around Papeete) along with pollutants discharged from illegal, artisanal or industrial activities (although these are few), leaching in paved areas, and sludge from the overflow of malfunctioning micro-plants due to lack of maintenance or inappropriate design. The lagoon can become extremely polluted as a result. Several studies conducted in the last 20 years confirmed the existance of such problems, mainly in Papeete harbour.

IN NEW CALEDONIA

Most districts have a stormwater system with open structures (concreted or unconcreted ditches), except Noumea where some networks are underground.

Flooding occurs frequently in several districts for a number of reasons:

- the tropical rainfall patterns and the geomorphology of a number of steep slopes;
- deforestation linked to mining and thedevelopment of residential areas, the proliferation of wild deer and pigs, loss of wetlands by infilling, agricultural drainage works;
- soil sealing by housing developments or artisanal and industrial areas, mainly in or around Greater Noumea.

These floods cause material damage and a high level of pollution in sensitive aquatic environments (rivers and marine environments).

IN WALLIS AND FUTUNA:

These two islands have very different characteristics.
Uvea island - Wallis - has no rivers. As there are no structures, stormwater infiltrates and supplies the lenticular table. Stormwater drainage is provided by the coastal road ditches. Catch basins have been built to complement these ditches to stop stormwater overflow running into the lagoon. The island is partly surrounded by mangroves and some have been made into taro plantations; these mangroves play an important desludging role and must be protected.

Futuna Island has no barrier reef and therefore no lagoon, its mountainous terrain generates important flows in each valley's small coastal rivers. Only the coastal strip is inhabited and has a very low impact.

L'île d'Alofi est vierge et ne porte aucun habitat

THE MAIN CAUSES OF WATER POLLUTION IN NEW CALEDONIA

- Domestic pollution (fecal coliforms, nitrogen, phosphorus and organic matter) mainly in the cities on the west coast;
- terrigenous deposits (heaby loads of SS) due to soil erosion, especially in mining catchment areas and all deforested areas because the soil has a loose surficial geology and is consequently easily dislodged;
- metals from the soil and mining waste;
- various pollutants linked to artisanal or industrial activities. With the exception of mining, there is no heavy industry in New Caledonia only processing. These activities' are scattered tjhroughout the island, but 70% are located in the Southern Province. They can generate pollutants including petroluem products, solvents, heavy metals, chemical products, and organic matter from food processing factories and processing plants;
- discharge of oolluting liquid effluents (leachates) from waste management and waste disposal centres;
- agricultural pollution linked to fertilisers, pesticides and herbicides (nitrates, phosphates, potassium used for cereal crops, livestock, gardening and horticulture, mainly on the west coast. The east coast is self-sufficient in food crop production and is cleaner;
- pollution linked to livestock farming which is very varied throughout New Caledonia; extensive cattle farms on the west coast and pig farms (nitrogen, phosphorus, potassium, organic material and fecal coliforms);
- pollution caused by aquaculture (mainly shrimp farming): salt nutrients, organic matter (faeces and unconsumed food), mainly on the west coast and in the Southern Province. Aquaculture causes major hyper-sedimentation and mangrove eutrophication;
- overflow of sewage treatment plants during the rainy season and waste from often malfunctioning individual sanitation systems;
- dumpsites and macro-waste that can end up being carried down the rivers during heavy rains.

2.1.3. POSSIBLE IMPACTS OF CLIMATE CHANGE

The main impacts of a changing climate are linked to:

- changes in rainfall patterns and in sea level:
  - an increase or on the contrary, a decrease in annual cumulative rainfall;
  - a decrease in the return period of heavy rainfall;
  - very heavy rainfall exceeding present levels;
- the intensification of cyclones: winds and the low pressures which generate them cause a temporary rise in water levels, in addition to the ongoing rise in sea level, with a corresponding reduction in the hydraulic slope at the outlet and consequently, in flow.

The rising sea level will gradually, but permanently reduce outlet capacity to the sea.

These changes will increase the previously described risks. The lagoons will suffer from increased deposits of terrigenous particles, debris and rubble, macro-waste from natural and/or anthropogenic sources sometimes loaded with pollutants, all of which will seriously degrade reef environments and related ecosystems by mechanical action, asphyxia, eutrophication and the effects of different chemical pollutants.

Inondation Mayotte, Cyclone Hellen, 30 mars 2014, source Firinga.com. Photo : NC

2.1.4. RECOMMENDATIONS FOR TECHNICAL ADAPTATIONS

A number of immediate measures are required to prepare for the possible changes listed above:

- based on an inventory of existing structures in each overseas territory, a survey is required of their status (degree of dilapidation, investigate incidents that have occurred during extreme weather conditions);
- rank structures as a function of possible risks and immediately resize those subject to major risks if necessary;
- start systematic hydrological calculations on catchment areas, taking into account the geomorphologic features of the sites, the vegetation cover and likely evolution based on foreseeable climate changes, but also on any developments planned in the catchment areas;
- regularly update flood risk prevention plans, to account for progress made in climate change projections;
- limit human settlements, housing and activities in sensitive areas;
- consider the progressive transfer of existing settlements that will be exposed and set aside land to prepare for such movements in the future;
- limit developments which have an impact on river hydraulics (deforestation, soil, sealing, etc.) and/or remedy them, for example by creating sedimentation-settling basins (like the mining sites in New Caledonia).

Generally speaking, completed and ongoing master management plans for water and sanitation do not appear to take the «climate change dimension» into account in their recommendations. As such structures are usually designed for a service life of more than ten years, it is essential to include the possible effects of climate change, in order to optimise existing and future master plans, and to be prepared to alter recommendations at each update, according to advances in our knowledge of climate change and possible technical innovations.

2.2. WASTEWATER

2.2.1. SUMMARY OF INFRASTRUCTURE AND STRUCTURES LINKED TO THE ROUTING AND TREATMENT OF SEWAGE WATER AND THEIR IMPACT ON THE NATURAL ENVIRONMENT

OVERVIEW

Sewage water is water affected by human activities after domestic, industrial, artisanal, agricultural or other uses. It is assumed to be polluted and has to be treated. Several different wastewater treatment systems are used:

Collective wastewater treatment systems
In most countries, especially in urban environments, wastewater is collected and transported through a sewage network (or sewage system) to treatment facilities (treatment plant, lagoon, etc.). Water which has undergone treatment is then released into the natural environment (into a river or the sea via an outlet).

Collection networks
These can be separate or combined:

- separate pipes are used for effluents and sewage and others just for stormwater,
- one pipe is used for all effluents.
- in the two systems, the treatment is never perfect during heavy rains, as flows are high and the effluents diluted. Treatment plants are saturated and the waste generally overflows and pollutes the natural environment.

Pumping stations are needed in low-lying areas or where gradients are not sufficient to carry the effluent to treatment plants and outlets by gravity.

Semi-collective sewage treatment

These are mini and micro-purification stations (20-500 PE) and small collective stations (up to 1,000 PE). In general, these are designed for housing developments, and for private houses, secondary schools and high schools when these buildings cannot be connected to a public network.

PE: POPULATION EQUIVALENT is a unit of measure defined in France under Article R2224-6 of the local authorities' General Code as an organic biodegradable load requiring 60 grams of biological oxygen per day for five days (BOD5),. In waste-water treatment, PE is the ratio of the sum of the pollution load produced during in 24 hours by industrial facilities and services to the individual pollution load in household sewage produced by one person during the same period (source Wikipedia).

In France, a population equivalent is 60 g of biological oxygen demand, 135 g of chemical oxygen demand, 15 g total Kjeldahl nitrogen (TKN) and 4 g of total phosphorus in a daily quota of 150 litres of wastewater.

Creating the population equivalent for public sanitation facilitates communication between technical services and the administration and helps determine the size of a wastewater treatment plant based on the polluting load.

Non-collective or individual sewerage treatment:

This is used when it is impossible to connect housing to a collective network. Domestic wastewater is treated in a pre-treatment monitoring tank followed by spreading sewage sludge on the soil or using sand filters.

Wastewater treatment plants

See box.

Outlets for treated water are usually located in streams and rivers or at sea.

In the marine environment, these outlets are usually made of cast iron or HDPE pipes which discharge at sites where the conditions (depth, currents, biological characteristics) are right to limit the impact on the environment and public health (depending on the required degree of processing). The route of the pipe is optimised according to the site's geomorphological and biological features and its exposure to strong swells, thus limiting the degradation of sensitive sea beds and damage to the pipe in extreme weather conditions. The pipe's fixtures are adapted accordingly.

Wastewater treatment plant outlet, French Polynesia
Photo © M. Porcher

Impacts on the natural environment

Normally, wastewater treatment plants considerably limit the impact of wastewater on the natural environment: less turbidity, fewer nutrient inputs (nitrates, phosphates) retention of sludge and some pollutants (heavy metals, pesticides, hydrocarbons), even removal of micro-biological pollution.

However, if the system does not function properly, the discharge from the wastewater treatment plant can lead to high concentrations

WASTEWATER TREATMENT PLANTS

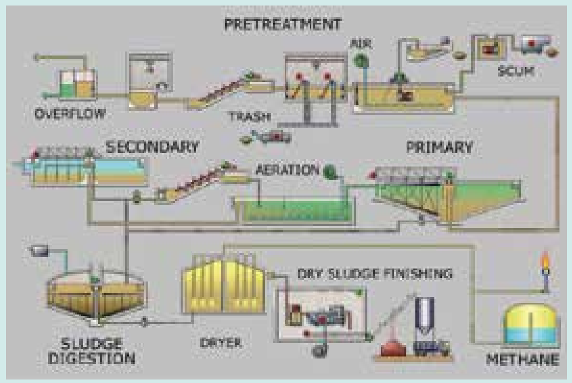
There are two main techniques to purify water: biological and physical-chemical processes

BIOLOGICAL PROCESS

A biological process is used for secondary treatment of urban and industrial wastewater. This process is mainly used to eliminate biodegradable soluble organic contaminants such as sugars, fats, proteins, because the physical-chemical process is less effective, more costly or difficult to implement. Biological treatment breaks down the biological matter using micro-organisms, mainly bacteria.

The different processes can be classified according to aeration and micro-organic conditions:

- aerobic biological processes or activated sludge. Activated sludge is usually used in French overseas territories,
- aerobic suspended-growth systems,
- anaerobic biological processes or activated sludge,
- anaerobic fixed-film systems.



Process flow diagram of a large-scale treatment plant.
(Source Wikipedia)

AEROBIC BIOLOGICAL PROCESSES

Pollutants are degraded by micro-organisms which are naturally present in the environment. Aerobic biological processes are based on the purifying properties of soil (planted reed filters, sand filters) or rivers (lagooning, activated sludge). The oxygen supply can be natural (from the wind or a cascade system) in small lagoon systems, or artificial (turbine or microbubble distribution) in «activated sludge» treatment plants. Bacteria can be suspended (activated sludge, lagoons) or fixed (planted trickling filters, sand filters, bio-filters) or RBCs. In an urban wastewater treatment plant with an activated sludge system, the process involves the following steps:

- pre-treatment i.e. screening, grit and oil removal,
- primary treatment: pre-settling basins to settle sludge and surface skimmers, with or without flocculation,
- secondary treatment: aeration and mixing, secondary sedimentation (also called clarification). Here, clarified water is rejected (except if tertiary treatment is required) and most of the settled sludge is returned to the aeration basin, whilst the excess is directed towards a specific circuit or storage tank,
- possibly tertiary coagulation-flocculation treatment or chlorine or ozone disinfection (to destroy pathogenic germs),
- secondary treatment may include anoxic stages to reduce nitrates.
- metals in solution can be neutralised by varying the pH of the water. This settles the pollutants...??????????

of nutrients at the outlet, causing eutrophication and hyper-sedimentation that are toxic for sensitive species like corals. This is followed by temporary bacterial pollution, which is dangerous for residents. The same phenomena can occur during heavy rains as the waste water treatment plants are overloaded and overflow, or may even be destroyed during high intensity cyclones.

2.2.2. SANITATION INFRASTRUCTURE IN FRENCH OVERSEAS TERRITORIES

IN OVERSEAS TERRITORIES (DOM)

The wastewater treatment systems in the five French overseas territories differ because the geography, demography and socio-economics in each territory are very different, as is their urban density. Their objectives are behind those of mainland France (Nicolas Richez, 2011).

Collective wastewater treatment systems
Eighty percent of exisiting waste water treatment plants use an activated sludge system, the remainder use other systems, including lagooning, aerated lagoons, membrane filtration. However, some systems are not suitable for marine conditions because they are too technical or the cost of maintenance is too high.

Wastewater treatment plants (WWTP) and sewage treatment
There are currently between 150 and 200 WWTPs of over 2000 PE in French overseas territories.

The largest plants are located in:

- Reunion Island: Grand Prado in Saint Denis (160,000 PE);
- Martinique: Dillon in Fort de France (85,000 PE);
- Guadeloupe: Ponte a Donne, Jarry Baie Mahault (45,000 PE)
- Guyana: Kourou (30,000 PE) and Cayenne which is under construction (60,000 PE with a planned extension to 90,000 PE);
- Mayotte: Mamoudzou (40,000 PE).

Exisiting facilities are usually inadequate. The most common problems are:

- the ratio of purifying capability to total population is low (ranging from 24% in Mayotte to 85% in Martinique);
- the WWTP's self-monitoring systems are not always reliable;
- the operation and management of the WWTPs is not up to standard, for example in Mayotte only 6% function correctly;
- the choice of treatment systems is not always appropriate, their size does not meet real needs and the location of the facilities is not always ideal. Many treatment plants are overloaded as soon as they start functioning. High temperatures all year round mean bacterial processes are very effective, but the WWTPs that use the activated sludge (low sludge) systems overflow when intense short tropical storms occur, also because there are no effective separate sewage systems. Lagoons face the same problems, which reduce their efficiency, and as a result, large loads of suspended solids (SS) are discharged into the natural environment during heavy rains.
- many WWTPs deal with urban sewage as well as industrial and artisanal wastewater and stormwater;
- semi-collective sewage systems (mini and micro-treatment plants of 20 to 500 PE) and small collective (up 1,000 PE) systems have rapidly increased in number, due to housing developments, and the high rate of construction means there is a time lag between the construction of housing developments and construction of a collective WWTP;
- most small treatment plants are badly maintained resulting in overflows into the natural environment;
- there are also a large number of non-collective treatment plants (or individual ones) in the overseas territories; 60% to 80% of individual sanitation systems compared to less than 20% in mainland France and they are mainly located in rural areas. Between 90% and 95% of these facilities do not comply with official standards and discharge insufficiently treated wastewater into the natural environment.
- sewage collection networks: connection to collective networks is generally not sufficient, i.e. between 10% and 40%. Little information is available on these networks; very few diagnoses are carried out on them and as a result, they are often in poor working condition. Some were badly designed or poorly built and some are even on slopes. In some coastal areas, sea water seeps into the networks and disrupts the sewage treatment process.
- in addition, topographical changes and the tropical climate increases the presence of H_2S in pumping stations and storage tanks, making it dangerous to operate the networks and H_2S can cause rapid chemical corrosion of the pipes.
- sludge management needs to be improved in all the overseas territories. A number of technical solutions exist:
  - direct recycling via agriculture;
  - use of sludge drying beds, although this is difficult in a humid climate;
  - filter presses that can reduce water content from 96% to 40%, thereby reducing the volume 10 fold: sometimes the residue is incinerated.

Sludge is less problematic or has a low impact on the marine environment.

IN OVERSEAS TERRITORIES (COM)

IN FRENCH POLYNESIA

The information in the following paragraph mainly comes from a report written in 2009 by the ASPA Consultant for AFD «Economic costs of deficient sanitation in French Polynesia».

This document confirms the alarming situation concerning wastewater management in French Polynesia, which is similar to that in French overseas territories, and highlights a significant delay in building water processing plants.

However, wastewater management programmes are in progress, especially in Papeete.

First, the particular population density in French Polynesia has to be taken into account. The town of Papeete in Tahiti has a permanent population of around 130,000 residents, and there are two zones with a very localised high population density due to the presence of luxury hotels on Bora Bora and Moorea. The rest of French Polynesia has a more dispersed population. Papeete is the biggest town; the villages have maximum of 3,000 inhabitants.

All the low population density areas have individual sanitation systems, except some hotels which have a mini treatment plant whose treated effluent is discharged into the lagoon.

The urban area of Papeete is still does not have a collective sewage system. Only the town of Puna'auia has a treatment plant in which the effluent treated by physical-chemical system located 60 m from the lagoon. There are many small treatment plants (biological plants with suspended or fixed¬film growth systems with trickling filters or bio¬towers) and individual sewage systems in the rest of the Papeete urban area.

More than half of these small treatment plants do not comply with standards, and the situation of the individual sanitation systems is worse, meaning untreated or inadequately treated effluent flows into the stormwater networks and then into the lagoon. The rest of Tahiti has individual sanitation systems, also with a lot of untreated effluent running into the valley basins, where a lot of litter can also be found.

However, Papeete's liquid sewage master plan (SDAL) has been drawn up and is under way for the other areas. The first section of the collective sewage system is currently being built in the city centre, with a planned pipe outlet outside the lagoon.

Moorea island
Most of the island's luxury hotels are in the Ha'apiti area which has a sewage network and a sewage treatment plant with an effluent pipe outlet outside the lagoon. However, these facilities are not yet functioning. Elsewhere, there are individual sanitation systems except for a

few hotels who built individual treatment plants around the island.

Bora Bora has a collective system which serves the whole island with a collection network, a treatment plant, and a pipe outlet discharging into the lagoon, but at depth, and with a current that flows towards the channel and open sea.

Given their low population density, t**he other islands** are equipped with individual sanitation systems.

On the atolls, some luxury hotels and schools have WWTPs with activated sludge systems or bio¬towers and the treated effluent is discharged through pipes into the lagoon. The main problem on atolls is lack of water, rainwater is collected in tanks and freshwater from wells. However, 95% of individual sanitation systems in the villages are not up to standard and the freshwater table is affected by bacterial and physical-chemical pollution. Consequently it is essential that individual sanitation systems at least have a waterproof pit and drainage system before the effluent is discharged into the ground.

IN NEW CALEDONIA

The data below comes from a report on a study conducted by the A2EP and Roche group in February 2009 for the New Caledonian Government entitled « Report on sanitation in New Caledonia –inventory and diagnosis ».

The population of New Caledonia is 230,789 (ISEE 2004) distributed as follows:

- Greater Noumea = 63%
- North Province = 19%
- South Province = 8%
- Loyalty Islands = 9%.

With the exception of Noumea, no urban centre has more than 5,000 inhabitants.

COLLECTIVE WASTEWATER TREATMENT SYSTEMS

The main techniques are activated sludge systems or lagooning.

Wastewater treatment plants (WWTP)

There are 13 WWTPs in New Caledonia, of which six are in Greater Noumea and two are under construction, plus numerous micro-plants in private housing estates or schools.

The city of Noumea has six communal treatment plants with a capacity of 83,200 PE, for an estimated 127,000 PE sanitation needs:

- Riviere Salee: 8,500 PE
- Yahoue: 5,000 PE
- Tindu-Kamere: 4,700 PE
- Magenta: 4,000 PE
- James Cook 20,000 PE
- Sainte Marie Bay 2, 000 PE

Currently, 45% of Noumea's households are connected to the network (95% connections are planned by 2030). The WWTPs' capacity starts at 50 PE (for micro-plants) and the largest is is the Koutio plant in Dumbea with 12 700 PE.

There is also a significant amount of treatment by lagooning. The recent lagoons of Bourail and La Foa are well adapted to any changes in loads and flow rates, which is not the case of a number of other treatment plants.

Wastewater collection networks

Public networks are in urban sectors and in recent housing developments where micro-plants have been built. They are mainly single units which consist of underground pipes or open ditches, or a combination of the two. These networks collect effluents from septic tank or individua users.

When a single unit is part of a sewage network, stormwater overflows are usually added to avoid overloading the pumping stations and local treatment plants downstream.

The biggest network is in Great Noumea, it is 340 km long, 60% in units and 40% in a separate system. Part of Dumbea's southern sector has a separate system; the Mont-Dore district has no WWTP and wastewater from septic tanks often goes into the stormwater network. During heavy rains, many outflow points cause pollution of the natural environmental.

Overall, the networks are in poor condition and there is little or no monitoring of their actual condition.

WALLIS AND FUTUNA

There are no wastewater treatment networks, all treatment is individual.

ARTISANAL OR INDUSTRIAL WASTEWATER

IN OVERSEAS TERRITORIES (DOM)

Overseas territories differ one from another.

In Guyana and Mayotte, there is little industry and exisiting companies are currently not considered to be significant sources of pollution for the natural environment.

In the Caribbean and Reunion Island

Industrial wastewaters are a major source of pollution for the natural environment (streams and rivers and the sea). In Guadeloupe for example, organic pollution by industries is estimated at 96 000 PE, which is more than twice that generated by the population. However, significant progress has been made in recent years and efforts are continuing.

Industrial pollution is mainly organic, it originates in the food industry which plays an important role both in the local economy and in exports. Most companies are involved in processing local fruit or distilling rum from sugar cane. Most sanitation problems are due to the absence of pretreatment before discharge, which saturates the WWTP and pollutes natural environment (increase in water turbidity and massive nutrient deposits, in particular, causing eutrophication).

IN OVERSEAS TERRITORIES (COM)

IN FRENCH POLYNESIA

Industry is limited because the domestic market is small, labour costs are high and there are no raw materials. Industrial activities are thus mostly artisanal and have only a few employees.

Existing industrial activities are in three main sectors: food processing, shipbuilding and manufacturing construction parts. About 80% of these activities are on the Leeward Islands, and in particular Tahiti, in industrial zones in the Punaruu valley, in Greater Papeete and vicinity. Aside from Tahiti, there are smaller zones in Moorea and Raiatea.

Small factories are located on steep-sided valleys and often discharge untreated effluents into rivers. The pollutants, organic matter and heavy metals, pollute the lagoons, especially Papeete harbour.

Forty percent of existing companies are in agribusiness, including the Tahitian brewery which has a beer factory in Punnauia and a fruit juice factory in Moorea. Both these factories produce highly polluting organic matter. However, they have a treatment plant which complies with environmental standards and a deep underground pipe outlet at sea (60 m from the shore in Punnauia). Pig and poultry farms in valley bottoms cause significant organic pollution.

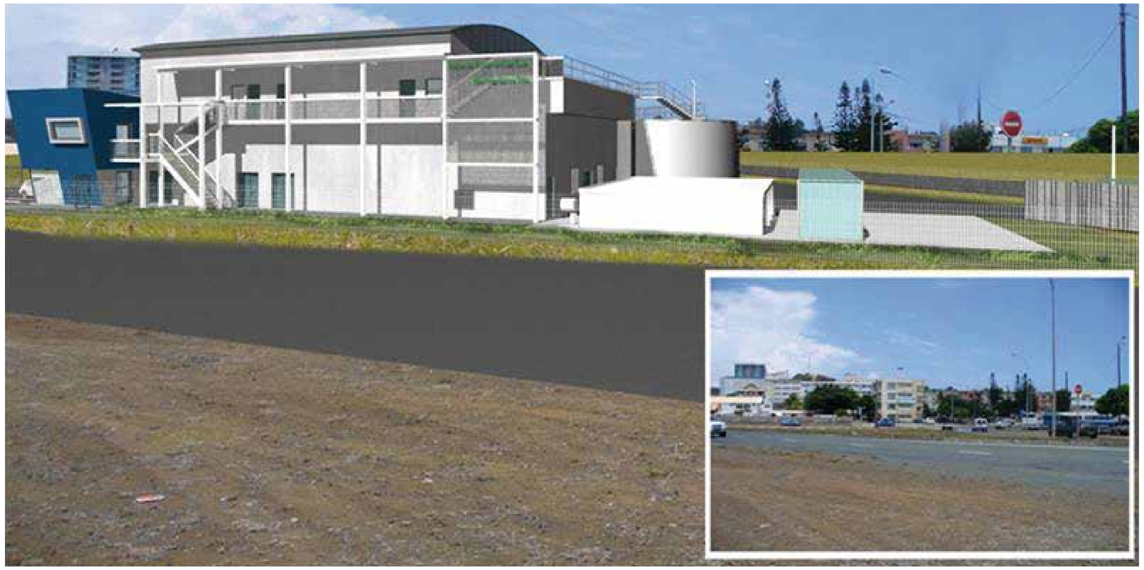
Extraction of river gravel is among the main contributors of suspended solids (SS) in the lagoons. In 2005, extraction in Tahiti accounted for 86% of the total flow of suspended solids (SS). Since then, management plans for gravel extraction have been established in the main valleys concerned and the situation has probably improved.

IN NEW CALEDONIA

In Greater Noumea, wastewater from the main industrial zones (Ducos in Noumea, the Numbo peninsula and Noumea's port zone with its hydrocarbon storage tanks) goes mainly into a single unit sewage network, but is not discharged into the communal WWTP.

Wastewater treatment plant

Industrial, artisanal and urban wastewater flows into the Anse Uare (Creek Sale) and Koutio Bay. In most cases, a basic type of pre¬treatment is applied consisting of settling, skimming oil and sludge.



Wastewater treatment plant. Photo: © All right reserved

In Noumea there are four industrial WWTPs. The other industrial areas are Normandie, La Coulee (in Mont-Dore) and Ziza in Paita.

Aside from Greater Noumea, medium-sized artisanal zones are mainly located on the west coast at La Foa, Bourail, Kone and Koumac. In the VKP area (Voh/ Kone/Pouembout), there are also rapidly expanding industrial zones and artisanal projects linked to the nickel treatment plant.

Exact information concerning the discharges from these industrial and artisanal activities and their impact on the natural environment is not available, and small businesses are subject to little control. Nevertheless it is perfectly obvious these discharges cause chronic pollution of the marine environment.

INDUSTRY LINKED TO MINING

The main industrial sites are:

- the SLN pyrometallurgical plant at the Doniamboen site which is directly linked to nickel processing, is responsible for major flows of pollutants to the Grande Rade, in addition to significant air pollution caused by gases emitted by the neighbouring power plant;
- two major projects are starting: the Vale Inco NC hydrometallurgical plant in the far south of New Caledonia, and the Vavouto pyrometallurgical plant in the VKP area in the north. The high level of pollution from these types of factories is due to heavy metals which end up in the marine environment.

But the three factories already are - and will continue to be - subject to rigorous environmental monitoring.

Other industrial mining sites enrich the ore before it leaves the site, transportation like the SLN Tiebaghi and SLN Nepoui cleaning sites. The discharges from these facilities into the sea are also subject to strict monitoring.

IN WALLIS AND FUTUNA

There is no industry in Wallis and Futuna.

2.2.3. POSSIBLE IMPACTS OF CLIMATE CHANGE

Water treatment plants are still being built in low-lying areas, i.e. on coastlines or next to river outlets and consequently risk submersion.

In addition, their outlets are exposed to swell, and rising waters could significantly reduce their hydraulic gradient and hence their flow.

The rising water level could also have serious consequences for certain treatment plant basins which could disgauge when emptied.

If the forecasts of increased heavy rains are confirmed, combined sewage systems will run a high risk of clogging and as a result, more untreated waste will be discharged into the natural environment.

Treatment plants should not be affected by rising temperatures (high oxygenation parameters and bacterial seeding).

It will no longer be possible to improve sanitation in low-lying coastal areas.

High winds do not directly affect hydraulic structures, but trees can be blown down and block outlets.

High winds, the low pressures that generate them, and stormwater cause water levels to rise which often reduces the hydraulic slope of the outlets. For that reason they may need elevating in order to evacuate effluents.
Existing lagooning stations may be too small if heavy rains are more frequent, which will result in physical and biological pollution of neighbouring natural environments.

2.2.4. RECOMMENDATIONS FOR TECHNICAL ADAPTATION

In the future, whenever possible, stormwater and wastewater should be separated.

In combined sewage systems, at least small overflow outlets should be installed to limit the disruption of water treatment plants during violent storms.

Treatment plants which are at risk from « high swells » should have enhanced protection.

Pipe outlets in areas where there is a risk of hydrodynamics and silting will also need protecting, and if necessary adapted to the rising water level, for example, using recovery systems.

In the case of a rise in the sea level, empty tanks will have to be stabilised to prevent them being lifted up by the water pressure.

2.3. WATER CONSUMPTION AND DRINKING WATER SUPPLY SYSTEMS

2.3.1. SUMMARY OF INFRASTRUCTURES AND STRUCTURES LINKED TO DRINKING WATER SUPPLY SYSTEMS

In addition to simple watering points, human activitives have required the construction of dedicated structures in catchments:

- wells were originally dug by hand, but the depth of the water table and the growing demand for water for a variety of uses means deeper wells are now required. These should enable access to water tables with a better flow rate and/or that are less polluted,
- reservoirs or pumping stations, pipes convey the water from its source to the end user,
- drinking water treatment plants. This kind of plant consists of:
  - an extraction point, followed by sieving and screening,
  - a settling pond with or without the addition of a flocculation adjuvant,
  - a series of gravitational filters (slow filtration) or pressurised (fast filtration),
  - a chlorination-disinfection unit and Ph (lime) correction,
  - possibly an ozone tower,
  - possibly a series of activated carbon filters,
  - a chlorinating output unit to protect the network (an injection rate of 1/10 of «shock» disinfecting chlorine);
- industrial wastewater treatment plants;
- pipes that convey water to the reservoirs and distribution pipes;
- reservoirs to store water and distribute it with

sufficiently consistent gravitational pressure;

- discharge facilities and compressors which ensure an increase in pressure if required (pressure drop, the level of the groundwater table at certain sites and IGH);
- pipes for distribution of the water to users.

Wastewater treatment entails the discharge of effluents into the natural environment, after desludging and filter washing. The effluent is thus concentrated and also contains treatment products (flocculents FeCl3, (SO4)3Al2, «wac» disinfectants, etc.)

Small treatment plants which deal with good quality water only chlorinate to protect the network.

2.3.2. INFRASTRUCTURE LINKED TO DRINKING WATER SUPPLY SYSTEMS IN FRENCH OVERSEAS TERRITORIES

French Overseas territories use conventional equipment which complies with global standards.

In some sites, if water quality is adequate, it does not need treatment, only chlorination to protect the network (Uvea-Wallis and a number of islands and atolls with brackish lens waters).

(the Cayenne treatment plant in Guyana: the extraction point is located 60 km upstream from the estuary, which is the limit of saltwater during storms).

In some rural and natural areas, there are no drinking water supply systems because the population density is very low.

High pumping rates mean water is removed from aquifers faster than it is replaced by rainfall, as a result,, the groundwater level is decreasing on all five continents.

2.3.3. POSSIBLE IMPACTS OF CLIMATE CHANGE

When extraction takes place in open water, water treatment plants and their catchments are located nearby, and therefore more likely to be flooded. In some overseas territories, extraction is by pumping in low-lying areas (atolls), and the facilities are at risk of submersion. Other facilities may also be at risk, although usually to a lesser extent, pipes in particular burst in some parts.

The main impacts of climate change will be due to two different types of changes: rainfall and rising sea level.

RAINFALL

Two scenarios are possible, depending on the region:

- first, limited rainfall, meaning the water table is not replenished. This can result in periods of low water flow when distribution will have to be interrupted or selective measures introduced (stopping irrigation of crops that require a lot of water,, for example, corn);
- second, more frequent and more violent rainfall, which reduces infiltration and increases runoff. During heavy rainfall, turbidity is such that it is no longer possible to treat it and comply with standards. In this case, the distribution of drinking water must be interrupted. Frequent violent rainfall means distribution will be increasingly at risk.

According to some forecasts, **the period of reccurring heavy rainfall will be shorter making such rainfall events more frequent.**

In some areas, an increase in the annual cumulative rainfall can be expected, but a decrease in others. Very heavy rainfall, exceeding present levels, is also to be expected.

In parallel, the slow rise in sea level is causing a rise in lens groundwater levels, in some low areas these will then be aboveground, thus threatening the water supply.

In coming decades, with the continuous increase in the density of coastal populations and the resulting freshwater extraction, the rise in sea level and lack of infiltration, **the risk of saltwater intrusion into lens groundwater tables will increase.** Building hydrodynamic models to assess water mixing conditions in aquifers is highly complex; they depend on the hydro-geological structures and capillary changes, seasonal flows, variable marine pressures due to different tidal ranges and high tides and storms. This rise in water levels makes low-lying structures more vulnerable to flooding.

2.3.4. TECHNICAL ADAPTATION RECOMMENDATIONS

To be carried out:

- different water needs (human, industrial, crop and livestock farming), and foreseeable increases should be estimated;
- the resources and their sustainability should be assessed;
- the current performance of the network should be assessed along with ways to improve it, to optimise extraction levels;
- critical parts of structures that are at risk of deterioration during violent weather conditions should be identified;
- these parts of the networks should be reinforced;
- waterstorage facilities and reservoirs, should be constructed wherebthere is a risk of water shortage;
- settling tanks should be constrcuted for highly turbid water;
- piezometers should be installed to monitor groundwater and saltwater intrusions;
- when appropriate, funding plans should be drawn up and resources prioritised.

(Source:brgm:http://www.brgm.fr/projets/explore-2070-relever-defi-changement¬climatique).

Impacts of climate change on the natural environment and on drinking water supply systems are:

- rising lens groundwater tables which can reduce their volume or even make them disappear;
- increase in concentrated effluents from waste water treatment plants discharged into the natural environment due to high turbidity during increasingly violent rainy periods;
- a risk of toxic pollutants from agricultural plant protection products (especially HCl, NaOCl, Cl2, FeCl3, (SO4)3Al2) stored at sites damaged by flooding and released into the natural and coral environment. These storage facilities have to be protected.

Modernisation of the WWTP Le Port – Possession, Reunion. Photo ©AFD (Agence Française et Développement)

2.4. COASTAL PROTECTION STRUCTURES

Like coastal zones all over the world, the French overseas territories suffer from beach and land erosion due to strong swells, including those caused by cyclones. The expected effects of climate change (rising sea level and increased intensity of cyclonic swells) will increase both erosion and flooding.

There are two types of flooding

- Flooding in low-lying areas (especially coastal marshes and mangroves, low coastal plains or embankment slopes on reef flats)
- Temporary storm flooding («episodic flooding of coastal areas due to severe weather conditions (strong depressions and high winds) and exceptionally high tides» (Garry et al. 1997).

The Coastline Risk Prevention Plan (MATE/ METL 1997) distinguishes between different types of coastal flooding:

- «surges» when the sea level is higher than the protection structures or dunes;
- «flooding by heavy seas» due to overtopping;
- «a dune line bursting or being destroyed after intense erosion» or «dykes and defence structures bursting» when the topographic level inland is below sea level.

All other things being equal, the rising sea level will result in an intensification of these phenomena.

French overseas territories all have extensive coastlines which were - and still are - interconnected and are served by port facilities. Defence structures were first built around the ports and second around tourist facilities. As most French overseas territories are islands, many protective structures were required against the sea's actions. *Consequently, the impact of climate change should be taken into account when managing existing structures and when designing future ones.*

2.4.1. SUMMARY OF COASTAL PROTECTION INFRASTRUCTURE AND THEIR IMPACT ON THE NATURAL ENVIRONMENT

OVERVIEW

These structures can be classified according to their function, design, type of materials used and their size:

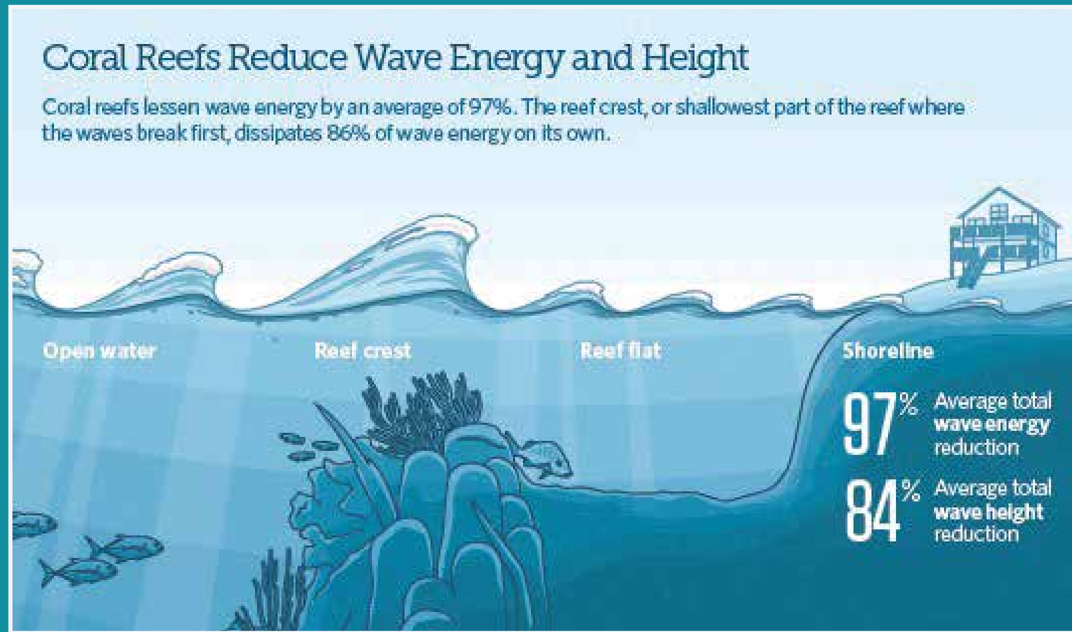
- **land protection and embankment slope structures:** linear structures built parallel to the coast: flood walls, low walls and rock or concrete structures (cubes or unreinforced Concrete Armour Units: ACCROPODE™ or Tetrapod units as protective structures for large coastal roads, airport runways or industrial port zones;
- **beach protection structures:** groynes, breakwaters (rocks or concrete blocks)
- **dykes to protect ports and marinas** (concrete walls and/or an outer layer of rocks or concrete blocks (cubes or Accropodes). Dykes are made up of layers of grit, varying in quality depending on the structure);
- **ecological protection:** detrital levees and artificial dunes, re-sanding beaches and replanting dunes or upper beaches, restoring coral reefs, creating artificial reefs, replanting seagrass meadows and reinforcing or restoring mangroves;
- **natural structures** (coral reefs, seagrass meadows, mangroves, beaches, dunes, rock beaches and gravel bars. *It is essential to preserve or restore them, given their crucial role in protecting the coast, over and above their biological role.*

MAJOR ROLE FOR CORAL REEFS IN COASTAL PROTECTION

Many studies have shown the natural breakwater effect of coral reefs. A recent study 'The effectiveness of coral reefs for coastal hazard risk reduction and adaptation' (Filippo Ferrario, Michael W. Beck, Curt D. Storlazzi, Fiorenza Micheli, Christine C. Shepard, Laura Airoldi - Nature Communications) confirmed and quantified their role and found that, on reaching the shoreline, coral reefs reduce wave energy by 97% (the reef crest reduces wave energy by 86% and a reef flat 65% of the remaining energy). Likewise, **the reef reduces wave height on the shore by 85%** (the reef crest reduces the breaking wave height by 64% and the reef flat 43% of the height thereafter). The study also found that on the reef flat, the 150 m closest to the reef flat crest reduce these residual waves by 50%. This shows that even relatively narrow reef flats are effective. The key parameters in reducing waves is the reef flat's water height (significantly higher than in open water) and the roughness of the coral, but its coefficient varies depending on the species (branching or encrusted corals do not have the same roughness coefficient).

The study also showed that an artificial breakwater and a coral reef are just as efficient. The breakwater reduces wave height by 30 to 70% and the reef by 51 to 74%. The authors concluded that the restoration of a degraded coral reef is around 15 times cheaper than the construction of an artificial breakwater.

The role of mangroves and seagrass meadows: mangroves play an important role in protecting not only the coastline, but also its inhabitants. It is estimated that the roots and vegetation of a 200 metre wide mangrove can absorb 75% of the swell's energy and sharply reduce the risks of coastal degradation behind it, protecting its infrastructure and bordering populations. During the 2002 tsunami, which hit Indonesia hard, large mangroves in coastal areas helped to limit mortality of the coastal population mortality and damage to infrastructure.



Source : F. Ferrario, M.W. Beck, C.D. Storlazzi, F.Micheli, C.C. Shepard, and L. Alroldi, «The Effectiveness of Coral Reefs for Coastal Hazard Risk Reduction and Adaptation, "Nature Communications" (2014), doi : 10.1038/ncomms4794 - © 2014 The Pew Charitable Trusts

GENERAL COMMENTS ON THE DESIGN OF COASTAL PROTECTION STRUCTURES

ROCK STRUCTURES

Most of these structures are made up of layers built from the core outwards, with either very fine (silt, with alterite type characteristics) or coarser backfill materials (blocks and rubble). This core is protected by one or more layers of rubble or rock that increasie in size outwards, ending with an outer layer made of larger rocks or concrete blocks. A geotextile underlayer is often placed between the rubble core of the structure and the rocks to prevent loss of the finer material due to the effect of swell and destabilization of the structure's core. The outer layer is made of rock or concrete, depending on its use. The revetment slopes typically vary between 1/3 and 1/4. The offshore side of port and marina protection dykes is usually protected by large blocks of rock whereas smaller blocks or vertical concrete docks are used for the harbor side. The wing walls are reinforced by larger rubble mounds in exposed areas.

CONCRETE STRUCTURES

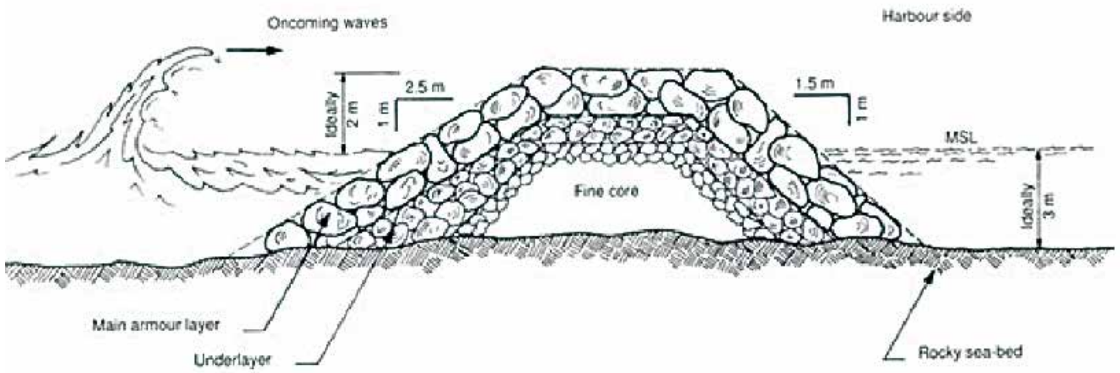
These are either mixed structures (rockfill dykes topped by concrete flood walls) or vertical or sloping structures, built with concrete blocks

Examples of concrete structures, Marutea Atoll docks (Photo: SA Palacz)

(especially for older structures) or prefabricated concrete caissons assembled on site, and then covered with a concrete outer layer. Their anchors are sometimes on posts especially on pontoons and dolphins (ducs d'Albe).

IMPACTS ON THE NATURAL ENVIRONMENT

- **The impacts are linked to the design and construction of the structure:**
  - sedimentological and hydrodynamic changes linked to poor design which cause hyper-sedimentation, and create confined zones that facilitate eutrophication or increase erosion;



Examples of a structure's cross-section. Here a rubble mound breakwater type (source FAO building a fishing shelter).

  - disruption of the shore profile, prevention of sediment exchanges between the upper beach and shoreline, thus increasing erosion phenomena;
  - biological disruption within or along the shore profile;
  - during construction: destruction of sensitive areas in and around the construction site, deposits of terrigenous particles during earth moving and building the structure's core (depending on the type of materials used);
  - accidental pollution by diggers, trucks, etc.;

- **impacts of structures once they are in service:** Other than the effects mentioned above caused by poor design, the hydrodynamic phenomena that damage structures also have a negative impact on sensitive natural environments including coral reefs, seagrass meadows and mangroves;
  - direct functional effects: when building materials (blocks, concrete blocks, rubble) are dragged over reef flats during strong swells they cause local damage to coral formations;
  - hyper-sedimentation originating from either the fine construction materials used for the core of the dyke, or degraded land upstream from the coastal protection structures. These sediments can suffocate the corals and seagrass meadows and soil leaching can bring pollutants (pesticides, heavy metals, hydrocarbons) although in smaller quantities, into these sensitive biological environments;
  - high levels of accidental pollution, critical risks are leakage of hydrocarbons or highly toxic industrial products into the environment when industrial infrastructure or industrial port zones are located upstream from coastal protection structures, which, when damaged or destroyed by extreme swells, no longer fulfil their protective role.

It is therefore essential to conduct a diagnositic survey of existing coastal protection structures, and to repair them or consider building different structures or even dismantling them depending on the pressure on the site and on the potential impacts of climate change, in the short, medium and long term.

2.4.2. OVERSEAS TERRITORIES COASTAL PROTECTION INFRASTRUCTURE

French overseas territories differ in their coastal geomorphology, their economic activities, and in the nature and the size of their coastal protection structures.

The following structures are classified according to the size of the structure:

- **Type 1: Large coastal protection structures.** These are flood walls that are several metres high, protections with armoured layers made of large rocks or concrete blocks measuring several cubic metres and weighing between one ton and dozens of tons.

- **Type 2: Medium-sized structures.** These are the most common type, and protect most coastal infrastructure: average size or small ports and marinas, low to medium exposed waterfronts, embankments, beaches protected by groynes and breakwaters. They are protected by medium-sized rocks weighing hundreds of kilos up to 3 tons or by low or medium height vertical or sloping walls.

- **Type 3: Small structures.** These protections are mostly built by residents or small hotels in areas less exposed to risk. They are low walls or small rock protection structures weighing a maximum of a few hundred kilos.

All these structures are described in detail in the sections on large infrastructure.

REUNION ISLAND

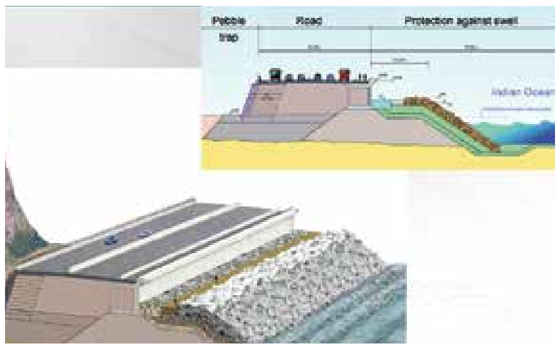
THE MAJOR COASTAL PROTECTION STRUCTURES

Such structures only exist on coasts directly exposed to the sea, i.e. not protected by a reef flat: the dykes' main armour layer is made of large rocks or concrete (cube or Accropode):

- at Gillot Airport;

Gillot Airport and Sainte Marie Port, at the end of the runway. Photo: © DTP Terrassement

- along some coastal roads like Saint Denis south coastal road, at the foot of steep cliffs (this road is the subject of a very large «New Coastal Road» project which will include very large embankments and viaducts built on the seabed);



Project: New Coastal Road - Reunion Island. © An environmentalist's journal.

- at the main ports: the industrial port area of Le Port de la Pointe des Galets, the ports of Saint Gilles, and Saint Marie at the end of the runway at Gillot Airport (photos below).

Reunion's industrial port. Photo: © Marie-Annick Lamy-Giner 9th June 2009

Port of Saint Gilles. Photo: © Hotel-les-creoles.com

MEDIUM SIZED STRUCTURES

- Small fishing and recreational sailing ports and marinas (the west coast and southwest ports of Saint Leu and Saint Pierre in reef environments; east coast ports of Sainte Rose and Sainte Marie on the coast exposed to the sea);
- urban embankment areas along the coastline, often near coastal ports and beaches. The outer protections are generally a main armour layer of large rocks weighing from hundreds of kilos to several tons.

Port of Saint-Leu located on a reef flat. Photo: © Sea-Seek.com

Port of Saint Pierre adjoining a reef flat. Photo: © Sea-Seek.com

SMALL STRUCTURES

Walls, low walls and rockfill embankments protecting land (urban areas) and beaches. If these protections are made of blocks of rock, they are generally smaller (weighing a few hundred kilos or a few tons). There are not many on Reunion Island.

MAYOTTE

MAJOR STRUCTURES

They protect the runway at Pamandzi Airport, the Longoni industrial port area and the southern exit of the Mamoudzou bypass (from Mamoudzou to Passamenti). This ring road borders or crosses a mangrove.

MEDIUM SIZED STRUCTURES

The port of Mamoudzou (concrete walls, docks and medium to small sized rocks) and coastal protection of these developments;

Mamoudzou: Medium sized rock embankment protecting the new market. Photo: Philippe Mathieu

The coastal protection structures in the east coast cities of Chiconi and Sada are also in this category.

Medium sized rock protection – Chiconi, Mayotte. Photo: © Dem Boitcha

SMALLER STRUCTURES

There are very few of these structures, which are simply small rock protections or low walls built by local residents.

EPARSES ISLANDS

Access is only by air, there is no port infrastructure or protection structures along the coast, boats anchor offshore.

WEST INDIES

GUADELOUPE, SAINT MARTIN AND SAINT BARTHELEMY

MAJOR STRUCTURES

These include the airport runway, the port, Pointe a Pitre Ferry Terminal and the industrial port of Jarry Baie Malhault (deep water port) and the Port of Basse Terre and adjoining coastal area, linear protection of the seaside boulevard with large rocks (exposed to the sea). The small port of Dehaies has a large rock breakwater and big concrete cube wing walls (1.5 m high). A major port expansion project is underway at Pointe Jarry.

MEDIUM SIZED STRUCTURES

Dozens of these structures are distributed around the island and its dependencies. These facilities are mainly:

- fishing ports and marinas, some moorings with a dock protected by rocks;
- facilities linked to hotels, consisting of marinas and a number of beach protection works,

especially on the southern coast of Grande-Terre between Le François and Gosier. The most important structures are marinas in St. Francis, Bas du Fort in Pointe a Pitre and the Rivere Sense in Basse Terre's southern tip.

Gosier aerial view (Guadeloupe) - Beach Protection: groynes and breakwaters with medium sized rocks. © Google Earth

SMALL STRUCTURES

There are relatively few in Guadeloupe and those there are mainly protect beaches, hotels and waterfront properties; they are walls, low walls and small rock protections. All are located along Marigot Saintes Bay (see photo) and are also relatively common in Saint Martin (on the shores of Simpson Bay in the Baie aux Prunes, Baie Longue, Grand Case).

Saintes: Marigot Bay - walls and waterfront homes
Photo: © Denise Pelissier

Small rock groynes: reed beach in Capesterre – Belle Eau in Guadeloupe. Photo: © Jojyba

LA MARTINIQUE

MAJOR STRUCTURES

The only major structures are the airport runway and the industrial port of Fort de France. An extension project is underway.

MEDIUM SIZED STRUCTURES

These are around a dozen ports, marinas and beach hotels, or coastal roads defences.

Trois-Ilets Marina (Martinique) © Magic Club travel

SMALL STRUCTURES

Relatively few small structures protect a few hotels and coastal populations, they consist of small rocks, walls and low walls.

SOUTH PACIFIC

FRENCH POLYNESIA

MAJOR STRUCTURES

The only major structures are the ports of Papeete and Faratea in the Taravao peninsula (second most important French Polynesian industrial port and Faaa airport runway);

The port of Papeete - Large flood walls and rocks.
Photo: © eminatetcie.canalblog

MEDIUM SIZED STRUCTURES

There are many medium sized structures which protect virtually all the French Polynesian airport runways (see chapter on Airports) and small ports and marinas (around 50 in French Polynesia);

Runway on a reef flat. © Photo of Gruyere Airport

View of Uturoa with its marina and in the background, the airport runway on a reef flat. Photo: © Sea- Seek.com

SMALL STRUCTURES

There are many small struxtures in French Polynesia because the coastlines are generally relatively well protected from open sea swells by a reef complex, consisting of a fringing reef, a quite narrow lagoon channel (but large enough to generate an important fetch) and a barrier reef. Most small structures built are parallel to the coast, and consist of low walls and/or rocks to protect natural land, coastal roads or embankments built by municipalities, hoteliers and residents. They are built along the upper part of beaches or along the fringing reef flats, on the motus (lagoon side) and to protect artificial islands. There are also groynes which protect the beach against erosion, especially artificial beaches belonging to the hotels.

Examples of small structures:

Small artificial beach. Club Mediterranean in Bora Bora.
Photo: © M. Porcher

LA NOUVELLE-CALÉDONIE

MAJOR STRUCTURES

There are only a few:

- Noumea port and its industrial port area are closely linked to the mining industry (nickel) in Anse du Tir;
- large marinas: the Orphanage Bay Marina (embankments, T-shaped groynes and large rocks);
- Moselle Bay Marina: concrete docks and rocks.

Nouméa. Port de la Moselle. Photo: © Panc / noumeaport.nc

These are also found on Loyalty Islands;

- **Mare Island to Tadine:** a dyke with a concrete dock and outer protective wall with medium to large rockfill;
- **Lifou Island: Port We:** a dyke, concrete wall and large rockfill;

Vertical or sloping concrete walls protecting part of Noumea's seaside boulevards (Anse Vata and Baie des Citrons).

Noumea: Sloping wall along the Baie des Citrons coastal road

Nepoui mining port (New Caledonia) (by Hockers 19)

MEDIUM SIZED STRUCTURES

Most medium sized structures are along the New Caledonian coastline. However, since this coastline is linear, there are not that many, except in the urban area around Nouméa.

These structures protect coastal roads, marinas, small fishing ports, river estuaries, mining docks, and some beaches (groynes and rockfills at the top of the beaches).

WALLIS AND FUTUNA

WALLIS

MAJOR STRUCTURES

There are none.

MEDIUM SIZED STRUCTURES

There are only four (docks, breakwaters, small marinas) and large walls at the top of the beaches protecting villas, and/or the coastal road with low walls or rockfills, especially near Mata 'Utu.

FUTUNA

MAJOR STRUCTURES

There are none.

MEDIUM SIZED STRUCTURES

These protect the airport runway, walls to protect the coast, a dock and walls in front of villas, and local rockfills to protec the coastal road.

SMALL STRUCTURES

There are many small structures on Wallis and Futuna, mainly low walls protecting land or small rockfills built by local residents along unexposed coastal roads. There are also many small embankments on the reef flat, protected by low walls or rockfills.

As there is no barrier reef on Futuna, walls have been built on the edge of the fringing reef and often in tidelands resulting in the erosion of neighbouring lands.

IMPORTANCE OF COASTAL PROTECTION STRUCTURES IN COASTAL ZONES OF FRENCH OVERSEAS TERRITORIES
Geomorphologic location and environmental pressures

Overseas collectivities	Number of different types of coastal protection structures (definitions above)	Geomorphologic location	Environmental pressures Nil: 0, Low *, Average **, High ***
Reunion Island	Type 1: 5 Type 2: <10 Type 3: few	4 exposed to sea 1 reef habitat <5 exposed to sea <5 reef habitat	0 to *** 0 to *** * to **
Mayotte	Type 1: 3 Type 2: 3 Type 3: very few	In reef habitats and mangroves In reef habitats and mangroves In reef habitat and mangroves	** to *** ** to *** * to **
Eparses Islands: Tromelin, Juan de Nova, Europa, Glorieuses	0	coral islands	0
Guadeloupe, Saint Barthelemy, Saint-Martin	Type 1: 3 Type 2: between 30 to 40 Type 3: few to average number	Near reef habitats Near and very close to reef habitats and/or mangroves	** to *** * to **
Martinique	Type 1: 1 Type 2: between 20 to 30 Type 3: few to average number	Mangroves Coastal dune areas, seagrass meadows, coral reef mangroves	* to ** * to **
French Polynesia	Type 1: 3 Type 2: >50 Type 3: numerous	reef flats reef flats reef flats	** to *** ** to *** ** to ***
New Caledonia, Iles des Pins, Loyal Islands	Type1: <10 Type 2: around 60 Type 3: numerous	Near fringing reefs and mangroves	* * to *** * to ***
Wallis and Futuna	Type 1: 0 Type 2: <10 Type 3: numerous	Fringing reef flats	* to ** * to **

Table 3: Importance of coastal protection structures in coastal zones of French overseas territories, geomorphologic locations and environmental pressures.

alls and rockfills are intended to protect the mangroves which are often backfilled, with eroded mud banks (pseudo rotation of these banks to the northwest).

2.4.3. THERE ARE A NUMBER OF IMPORTANT POSSIBLE IMPACTS OF CLIMATE CHANGE ON COASTAL PROTECTION STRUCTURES AND CONSEQUENCES FOR REEF ENVIRONMENTS AND RELATED ECOSYSTEMS.

The main parameters to be taken into account are rising sea levels and the likely increase in the intensity of cyclones and hence o in coastal erosion and degradation, or even the destruction of protective structures during strong cyclonic swells. Submerging seas due to high swells combined with high floods after intense tropical rains will have serious consequences. Coral reef flats will accumulate rocks, concrete blocks, rubble and fine materials from destroyed structures, and deposits of terrigenous particles caused by leaching and soil erosion due to floodingupstream. Moreover, these matierials contain different pollutants leached from the soil.

The impact of climate change on coastal protection structures is described in the following chapters, with specific details on each major type of coastal infrastructure including its protective structures.

Cyclonic sea surges on Reunion Island's coasts. Photo: © AFP

IMPACTS ON COASTAL AND PORT PROTECTION STRUCTURES

The size of coastal and port protection structures is determined by marine forcing data and geotechnical conditions. The main hydraulic pressure originates from swells and the sea level. Climate change will have an impact on the geometry of the structures (Hawkes et al., 2010). Thus, the following main effects need to be taken into consideration: changes in offshore swells (average sea surges). It is difficult to predict how this will evolve as the impact of the swell depends on the position of the structureand also affects its bathymetry.

Despite these difficulties, studies on the consequences of these expected changes havealready begun in France. The Discobole project is analysing the significant increase in water depth in the vicinity of a test dam due to rising sea levels and evolving sea surges (Lebreton and Timal, 2009). This increase in depth creates difficult sea conditions near the structures which, in turn, damage rockfill layers, and cause higher wave overtopping. Another test structure is being used to analyse possible increases in offshore swells.

More general studies are being carried out as part of the Sao Paulo IPCC program (Intergovernmental Panel on Climate Change) and Theseus (Innovative technologies for safer European coasts in a changing climate), funded by the European Union. As most coastal and port structures in mainland France are in shallow waters, i.e., in areas where surge and swell are reasonably easy to assess, the structures are adapted to these conditions.

These studies showed that rising sea level is more detrimental than increasing swells offshore due to the likelihood of more intense storms. Based on a 0.6 to 1 metre rise in the average water level in 2100, the bathymetric surge in coastal areas will be close to the structures, which, in turn, will cause stronger swells to hit the coast. In the end, the pressure will be more severe and result in unstable rockfill dyke embankments and higher wave overtopping. These will have a serious effect on the stability of the structures, and on port operations and infrastructure protection.

These studies, which were based on the theoretical analysis of structural dimensions, enable the following conclusions to be drawn: an increase of one meter in the average water level means that structures located in shallow waters will need to be raised two meters to perform as well in terms of wave overtopping (Sergeant et al., 2010). In addition, the structures will be subject to a significant increase in stress. Thus, to maintain the same stability, the mass of the blocks protecting a structure in shallow waters will have to be at least doubled to cope with the future rise in sea level and increase in swells.

In parallel, studies were conducted on scale models to confirm initial results. In general, three ways emerged on how to adapt structures:

- limit wave overtopping (e.g. by altering the wall crest);
- improve the stability of the main armour layer (by adding an additional layer of riprap, making the slope steeper);
- reduce pressure (by building a new structure in front, by reloading sand).

These studies are still at the theoretical stage and regional forecasts of the effects of future climate change on current structures are not taken into account.

(Extract from the report: «France's 21st century climate, Volume 3 – Rising sea levels - S. Planton et al. February 2012-Ministry of Ecology, Sustainable Development, Transport and Housing»)

2.4.4. RECOMMENDATIONS FOR TECHNICAL ADAPTATION

The recommendations apply to different areas of decision making.

LAND PLANNING

As this guide focuses on coastal infrastructure, land planning approach is only mentioned in connection with our technical recommendations below: The broad guidelines in the French national Strategy for Integrated Coastal Management include:

1. drawing up a spatial plan of physical hazards, planning urbanisation and choosing developments;
2. drawing up 10, 40 and 90 year plans that take into account future changes in physical phenomena and weighing up the possible relocation of activities and assets as an alternative to stabilising the coastline in the medium and long-term, based on cost-benefit analyses;
3. setting up a joint territorial management unit to cope with the risks of coastal erosion and sea submersion, including a leader who will be in charge of drawing up a development plan for the territory and who will monitor its implementation by other actors selected for their different skills;
4. conducting cost-benefit and multi¬criteria analyses to justify the choices made in the operational coastal plan;
5. protection projects that destroy the natural coastline should only be considered only in densely inhabited zones or areas of national strategic interest, or they should be designed so that in the long¬ term the activities and assets can be relocated elsewhere;
6. adaptive coastal management techniques should be applied in areas with average population density (random urbanisation, etc.) or predominantly agricultural areas;
7. protecting and restoring coastal ecosystems (wetlands, sand dunes, mangroves, coral reefs, etc.) as they play an important role in reducing wave energy thereby limiting the impact of coastal erosion on activities and assets.

CAREFUL CHOICE OF COASTAL PROTECTION STRUCTURES

Coastal protection cannot be done on an ad hoc basis because such developments all have an impact on neighbouring areas. A comprehensive coherent view of coastal development for the entire region is thus a precondition, which is then broken down into homogeneous geomorphologistic zones: a bay, a large sandy coastline, a lagoon area, a wetland, an area with mangroves, etc. Each zone should then be considered jointly with the neighbouring and any functional interactions should be taken into account. The offshore sedimentological and hydrodynamic functions of this coastal zone must also be taken into consideration.

POST ACTION EVALUATION

Planning tools for coastal zones exist at the national level:

- Marine Strategic Framework Directive (MSFD);
- Integrated Coastal Zone Management (ICZM);
- coastal planning schemes (SMVM);
- coastal section of Regional Development Plans (SAR) and Management and sustainable development plans (PADD)
- Grenelle Environment Forum tools;
- urban planning documents including (Territorial Coherence Scheme (TCS) and Local Urban Planning (LUP), where coastal protection problems linked to climate change can be integrated. However, not all these documents take such problems into account and do not necessarily apply in French overseas territories. However, planning documents are available for French Polynesia (integrated management plans for lagoons).
- specific Risk Prevention Plans (RPP) documents on flooding and flood risks have been drawn up and are, being implemented or are planned.
- as part of the French national climate change adaptation plan (NAPCC), studies have recently been conducted to assess actions already undertaken concerning management of the coast and its vulnerability to climate change and a national integrated coastal management planning policy has been drafted.

We refer to the following documents:

National documents:

- «Coastline management» (QUAE Editions 2010);
- «National integrated coastal management planning strategy «(Ministry of Ecology, Sustainable Development, Transport and Housing-2012). This is a roadmap urging the State and local communities to acquire knowledge and develop local strategies that incorporate coastal erosion in public policies. It sets out common principles and makes recommendations for strategic integrated coastal management.

More specifically, we refer to the following on French overseas territories:

- CETMEF-CETE – West CETE (September 2012) - «France's vulnerability to coastal risks in her overseas territories » CETMEF/DI report;
- And «Overseas territories facing the challenges of climate change» the 2012 ONERC report the Prime Minister and Parliament.

Ahanlysis of these two documents showed that some Risk Prevention Plans (RPP) have been drafted for sea submersion and multiple hazards (flooding–submersion and landslides), but that some overseas territories lag behind due to delays in urban planning control policies. Different integrated coastal management schemes exist or are planned, but none incorporate the «climate change» parameter.

The study on the vulnerability of the coastlines in overseas territories coastlines highlights the risks that every territory may run, but also underlines that no documents have been published on coastal risks and that the location of the structures at risk is not specified, nor is a description of the risks provided. In fact the focus of the analysis is on risks faced by low-lying areas: buildings, transport infrastructure, industrial plants, and natural protected areas.

TECHNICAL RECOMMENDATIONS FOR EXISTING STRUCTURES AND FOR THE DESIGN OF FUTURE STRUCTURES

Old structures were designed empirically, based on experience and local knowledge.

The design of contemporary structures takes into account the average sea level (relatively constant over a given period) and wave height over a statistical period (e.g. centennial).

Several parameters that account for hypothetical future developments of a structure calculation need to be calculated:

- the average water level, ane the likely rise;
- the maximum wave height for a specified period, the increase in height will be partly due to rising water level, and partly due to temporary surges;
- the return period of surges should be shorter, not only due to the above point, but also because of a possible increase in severe weather conditions;
- the direction of the surge in relation to the shore, which is likely to evolve with rising water level.

Project developers will need to review the possible frequency of reoccurrence, the basic design of the structure in question, and to monitor plans for developments that directly affect the coastline (especially embankments, earthworks, dredging) or the area close to it (risk exposure).

CETMEF published an important reference document (http: //www.eau-mer-fleuves.cerema.com/publications-and-phototheque-r6.html), the following recommendations were taken from it:

«...existing structures must be consolidated, and/or reinforced, resized if their potential overtopping is unacceptable, studies should be based on statistical data, reliable data from a detailed analytical method that can forecast coastal hazards...».

A study of surge conditions, i.e. wave breaking and «shoaling» makes it possible to calculate the potential overtopping flow. The calculation will always be higher than sea level. It will require reliable data on surges and water levels as well as periodic data such as incidents, reoccurrences;

If these measures cannot be implemented, extreme weather conditions could require planned strategic withdrawal and the destruction of the structure concerned.

NB: It should be noted here that an actual ten-year statistical V Episode could not possibly reoccur within a 10 year period.

CHOICE OF A METHOD OF REINFORCEMENT

As part of the ongoing European THESEUS project, in the 7th Framework Programme, of Hans Burcharth of Aalborg University (Denmark), a method was designed to identify the most economic reinforcement method. CETMEF is in charge of reinforcing structures in this project.

The method involves ten steps:

1. identifying the structure's service life;
2. identifying the geometric and environmental pressures;
3. identifying both the future offshore swell and highest water level statistics;
4. determining the swell at the foot of the structure with respect to the offshore swell;
5. identifying the criteria needed to evaluate the performance of the reinforced structure;
6. determining the structure's weaknesses with respect to the selected performance criteria;
7. measuring the structure's required reinforcement;
8. calculating the cost of alternative types of reinforcement of the structure;
9. calculating the cost of damage to the structure for each alternative;
10. among the alternatives, selecting the most economic with respect to the service life of the structure.

ANALYSIS OF EXISTING STRUCTURES, THEIR POTENTIAL REINFORCEMENT AND/OR BUILDING NEW ONES

FOR MAJOR OR MEDIUM-SIZED STRUCTURES (see sections on the different types of infrastructure).

CETMEF is developing a method to conduct an inventory of existing structures and their condition which can be consulted at *http://www.eau-mer-fleuves.cerema.fr/publications-et phototheque-r6.html*

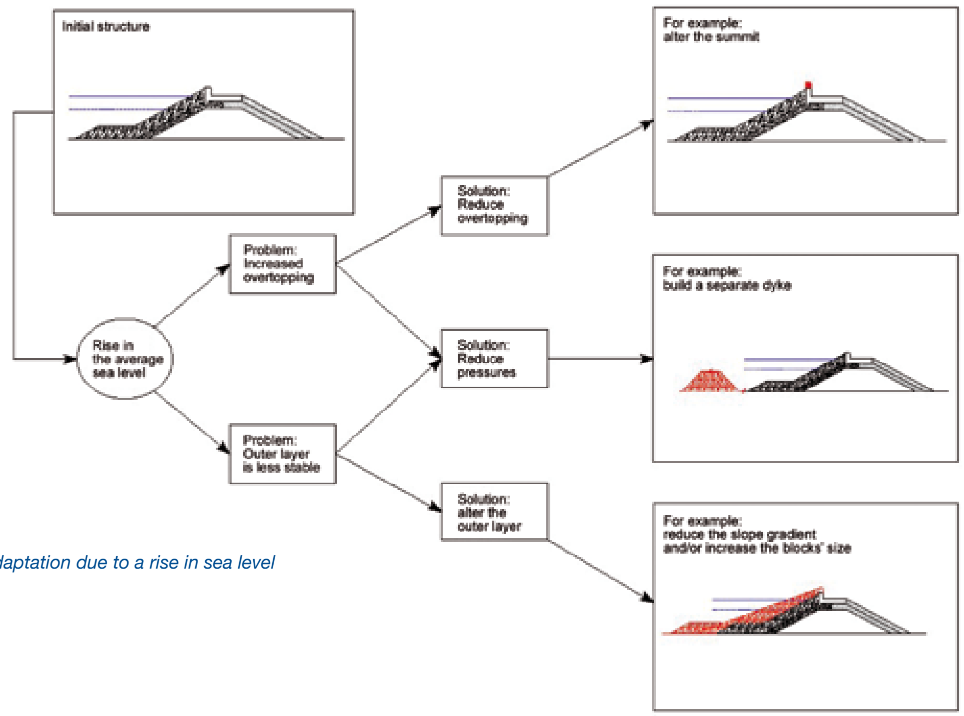
The diagnosis should take into account the technical dimensions of the structure, but also its environmental aspects:

- analysis of the impact of a degraded structure on sensitive neighbouring environments (coral reefs, seagrass meadows, coastal vegetation including mangroves). These observations should be taken into account if the structure is restored;
- special attention should be paid to local pressures originating upstream in the watershed. The potential erosive accumulation (land-sea) due to exisiting deposits from the watershed should be estimated and estimations should take future developments in these upstream areas into account. Reflection with watershed managers on hydrological and urban implications will be required to avoid increasing the risk of flooding or of accumulating materials (blocks, terrigenous particles being transported towards the coast), and if possible, these risks should be reduced;
- recovering existing structures will probably be complex; the conclusions of the SAO POLO study list the measures to be taken if a structure needs consolidating or new ones built (see diagram below). As these measures will affect the seabed, it is important to pay particular attention to the type of seabed (coral, seagrass meadows, etc.) both when choosing the method of consolidation and during construction phase.

FOR SMALL STRUCTURES
(usually built by individuals and coastal residents)

The following recommendations will have to be widely disseminated in view of the serious problems we face. The following actions are recommended:

- an inventory of all the coastal structures (walls, low walls, rockfill structures, artificial beaches) and planned developments that could have a negative effect on the stability of the coast: artificial channels dug into reef flats to allow access for boats, destruction of beach-rock along the shoreline to facilitate access to the water by swimmers and small boats, removing sand from beaches, dunes or on the reef flat and coral reef slopes;
- based on the diagnosis, awareness raising and training programmes should be organised for local residents;
- we suggest that structures that have a negative effect on the coast should be dismantled and structures that are adapted to the site's conditions built to replace them by eliminating vertical and waterproof structures, and promoting the use of ecological techniques and replanting of vegetation;
- coastal protection legislation will need to be significantly strengthened by increasing fines to deter offenders, especially for the following offenses:
  - destroying beach rock,
  - digging channels in the reef flat,
  - collecting sand and coral,
  - destroying coastal vegetation (trees, bushes, dune stabilising plants)
  - destroying mangroves.



Examples of dyke adaptation due to a rise in sea level (SAO POLO project)

Legislation concerning the speed of boats should also be strengthened; especially in some busy lagoon areas (the action of waves from passing boats is particularly damaging to small protection structures in coastal zones). In areas that are highly sensitive to erosion, jet skiing and water skiing should be prohibited if necessary or routes laid down well away from these sensitive areas.

Generally, wherever possible ecological or innovative technologies should be used for medium¬ size to small structures. Possible actions in this category are:

- planting vegetation to stabilize dunes and the upper beach
- re-establishing a sedimentary system on beaches by removing the structures that obstruct it;
- building artificial beach rock by simulating the natural one, in areas where it has been degraded;

Some examples of current techniques are shown below:

Photo Example of partly destroyed beach-rock and a basic diagram of beach-rock reconstitution (source: M. Porcher)

Photo Example of a protection put in place by a hotel in French Polynesia (source: M. Porcher)

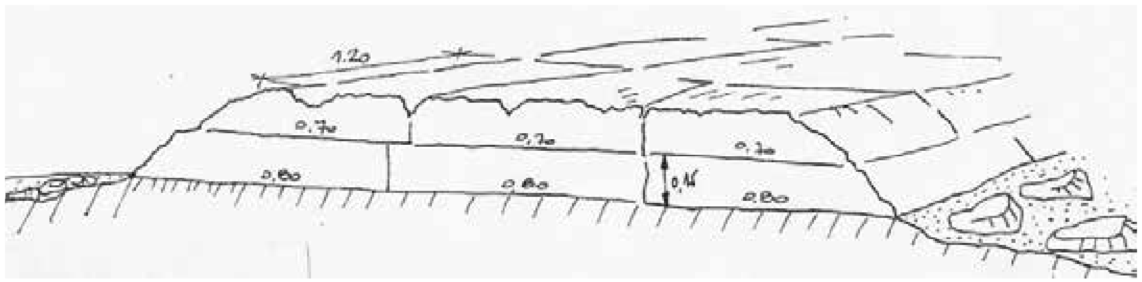
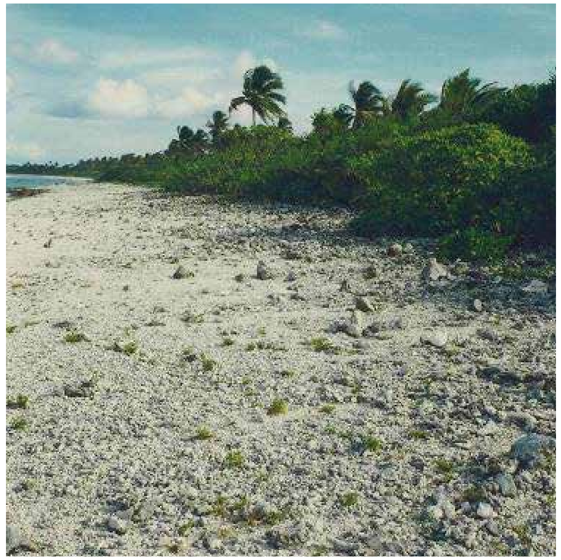


Diagram Example of a beach protection using mixed techniques: low slope re-profiling, laying mattress type gabions and sand filling;

Example of a concrete structure simulating a beach-rock in New Caledonia (source: M. Porcher)

Example of a concrete structure simulating a beach-rock in New Caledonia (source: M. Porcher)

Below are examples of artificial detrital levees simulating natural ones (slope, outer detrital layer and slope replanting). These types of structures have been very successful in French Polynesian hotel complexes.



Natural detrital levee near the structure.
(source : M. Porcher)

Project Overview (source: M. Porcher)

Artificial detrital levee under construction (source: M. Porcher)

Detrital levee after construction with vegetation (source: M. Porcher)

An example of artificial reefs that replicate natural reefs as closely as possible with sub¬caves, which enables rapid colonisation and in some cases, establishing local coral gardens (see example in Bora Bora):

Photos Massive concrete blocks simulating coral reefs with transplanted corals on the blocks (source: M. Porcher)

The protection of **mangrove areas** is an integral part of protecting the coastline. The most important recommendation is promoting restoration (replanting) of degraded areas and reinforcing mangroves that face serious problems in upstream areas. A necessary part of implementing or updating development plans in coastal zones, is preserving open spaces upstream from existing mangrove areas to enable them to expand, which will become possible with the ongoing rise in sea level. Upstream structures that prevent the growth of mangroves should be dismantled wherever possible.

Recommendations for research activities should focus on optimisation:

- modelling local climate phenomena;
- simulating extreme hydraulic situations in the vicinity of infrastructure and of the structures themselves (hydrology and hydrogeology);
- calculating flood risks coming from the watershed and from sea surges;
- calculating possible swells in the vicinity of the the structure;
- adapting the design of the defence infrastructure to be consolidated or built;
- closely observing climate change phenomena in the vicinity of infrastructure (increasing the number of measuring devices in weather stations near the site, tide gauges);

The recommendations in the previous paragraph are in «checklist» format to enable the diagnosticians to draft a coherent final document for all the projects concerned.

Mangroves, Guadeloupe. Photo: © Franck Mazéas

Aerial view of St François (Guadeloupe). Photo: © Franck Mazéas

CHAPTER 3

3/ KEY PUBLIC INFRASTRUCTURES

This chapter deals with major transport infrastructure: airports, ports, roads and energy supply facilities.

3.1. AIRPORT INFRASTRUCTURE

In 2013, the French Civil Aviation Service prepared a document (in French) entitled «A study on airport vulnerability to climate change Phase 2: Airport infrastructure vulnerability assessment methodology on the impacts of climate change»

The document is an evaluation tool which contains detailed information on airport infrastructure and airport vulnerability to climate change. It identifies the uncertainties of climate change and its potential impacts on airport infrastructure and airport operations. It also includes a method to calculate the likelihood of climatic hazards and

their impact on an airfield systems components, and an evaluation guide. This method could be tested and improved on a representative sample of airfields and a selected sample can be found in subsection 8 of the report. It includes the following airports in tropical French overseas territories:
Martinique-Aime-Caesar, TFFR/Guadeloupe

Pole-Caribbean, FMEE/Reunion-Roland Garros, Mayotte: FMCZ/Dzaoudzi-Pamanzi, New Caledonia: NWWW/Noumea-Tontouta, and French Polynesia: NTTT/Tahiti Faa'a, NTTR/Raiatea, NTTH/Huahine, NTTM/Moorea, NTTP/Maupiti and NTTB/Bora Bora.

This is a useful refrence document, particularly Appendix 1 which is a questionnaire for airport operators.

The analysis below focuses on the vulnerable aspects of an airport that could affect the natural environment.

Here we take a different approach from the one recommended in the TCAS report, which covers all the operations at an airport. The two approaches are complementary and airport operators should use them together.

3.1.1. SUMMARY OF AIRPORT INFRASTRUCTURE

An airport is an area where aircraft arrive and depart, manoeuvre on the ground, and park. It may include aircraft garages and/or maintenance facilities. Aviation company also usually have their offices at the same site.

The types of airport infrastructure will differ depending on its uses, which may be commercial transport of passengers or military activities. The terms used to distinguish the two are **'airport'** and **'air base'**. When the airport is not only used for one of these activities, it can be confusing, so we distinguish them by using the terms **«commercial aviation»** and **«general aviation».**

Each civilian airfield has a four letter code issued by .the International Civil Aviation Organisation (ICAO).

Each airport also has a three letter code issued by the International Air Transport Association (IATA) .

Juan de nova. Photo: © Google Earth

Mayotte airport. Photo: © www.mayottedepartement.fr

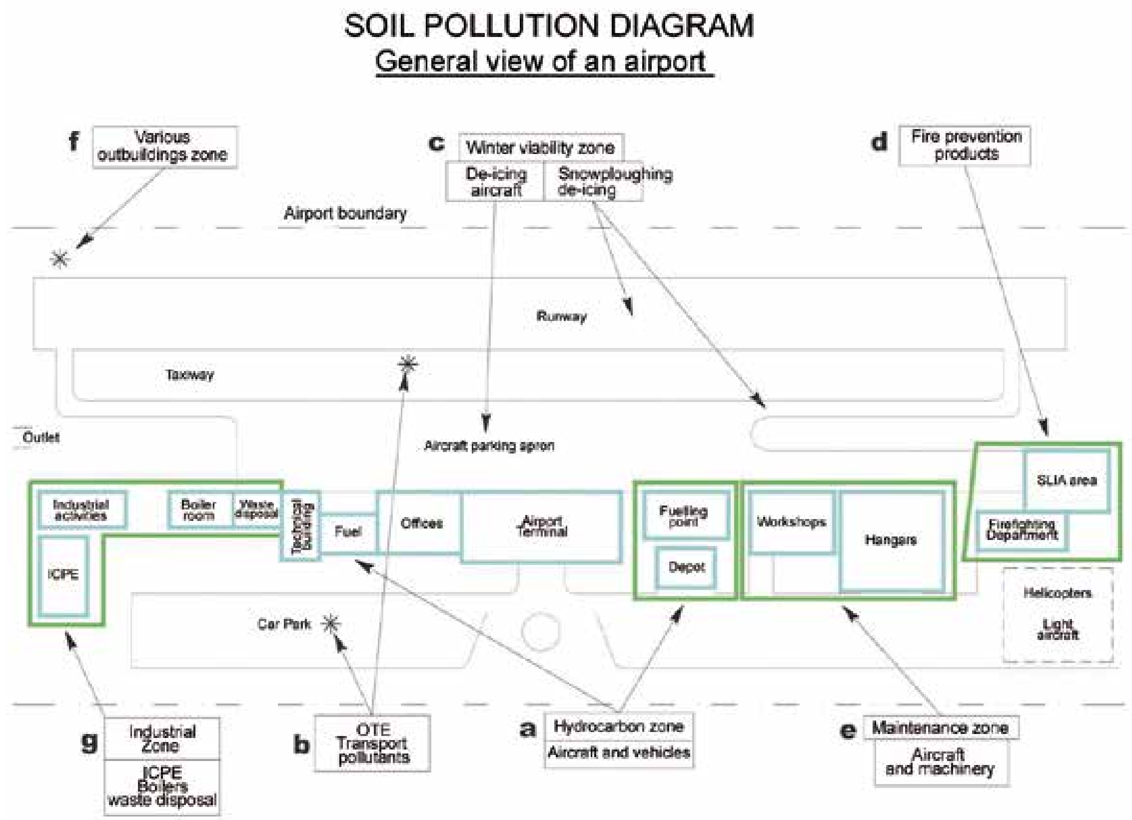
Bora Bora Airport. Photo © Bora Bora Airport

An airport usually has different aeronautical zones:

- a take-off and landing area with one or more runways bordered by flight lanes and runway clearance zones, and maybe stopways;
- a manoeuvring area to get to the runway (taxiway);
- an apron where passegers board or disembark, load, or mail or cargo is unloaded, fuel tanks are filled or emptied, planes are parked, and maintained;
- a set of light signals and navigational systems;
- an air movement control system around the platform consisting of at least a signalling area and windsock;
- a refuelling zone and fuel depot sometimes with an oil hydrant system;
- buildings used as garages or for maintenance of aircraft and storage of firefighting equipment.

An airport consists of two main areas:

- a public area «land side»: this includes access to the airport (road or maritime), car parks (passenger and freight), passenger and cargo terminals, offices;
- a restricted «air side» area, under the aviation authorities' control.



General view of an airport
(plate from the: «TCAS Technical Note on the airport soil pollution issue; 2007» report)

Overview of an airport (source: “TCAS Technical Note on the airport soil pollution issues (2007)”)

When there is a need to accommodate a high volume of traffic and heavy aircraft, flight lanes will be wider, longer and able to withstand heavy loads. The signalling system will be adapted for day and night use, in all types of weather, using light beacons. There is a control tower for the air traffic controllers on the ground in the vicinity of the airport.

The flight lanes and runways for takeoff and landing are generally coated in asphalt concrete; but may be made of concrete, grass, or coral materials (on small islands). They are identified by a unique number which is its position in degrees with respect to magnetic north. Light aircraft runways are generally 1000 m (B) to 1500 m (C) long and 25 to 45 m wide. Runways at airports with commercial airline traffic (D) are normally 3000 m long and 45 to 60 m wide.

Runways are usually bordered by grass clearance zones, where in the event of an overrun, the aircraft can manoeuvre without damage. The taxiways around the runway have sea defence protections if required.

Consequently, it is not possible to dig ditches next to a runway. Water is collected in «Satujo» concrete slot gutters, where necessary.

Airports can have several intersecting runways so that aircraft can face the wind and avoid a crosswind, or parallel runways to cope with high traffic; Except for old USAF runways on Bora Bora no airports in French overseas territories have several runways.

On small airfields, which are common in Overseas territories, there is limited infrastructure and hardly any maintenance and industrial activity zones.

3.1.2. IMPACTS OF AIRPORT INFRASTRUCTURE ON THE NATURAL ENVIRONMENT

Aerial view of Mayotte airport’s runway, bordered by a reef flat. Photo © Michel Porcher

Pointe a Pitre Airport surrounded by a mangrove environment (DGAC report)

The construction airport infrastructures has an impact on the natural environment, as it does when the airport is **the operating.** Airport operations cause pollution that affects soils, vegetation, groundwater tables and any sensitive environments in the vicinity (mangroves and coral reefs in inter-tropical areas). An airport is mainly made up of impermeable surfaces (runways, parking zones, etc.) and any run-off from these surfaces can cause the following types of pollution:

Chronic pollution: this type of pollution is generally very low, but likely to accumulate over time. It is due to airport operations; aircraft and vehicle exhaust fumes, maintenance (cleaning, repairs), re-fuelling (fuel and oil), fire drills, and rubber marks from tyre wear,etc.

Seasonal pollution (does not apply to inter-tropical areas): due to de-icing runways, parking areas, and aircraft.

Accidental pollution: spills of large quantitites of fuel/oil and other hazardous materials during accidents.

These types of pollution are taken into account by airport designers. Stormwater and runoff from aircraft parking areas are collected and channelled to oil separators or via retention basins that can contain accidental and chronic pollution from airport operations.

Wastewater is treated by the city’s wastewater treatment plant. However, there may be residual pollution at the effluent outlets into the environment.

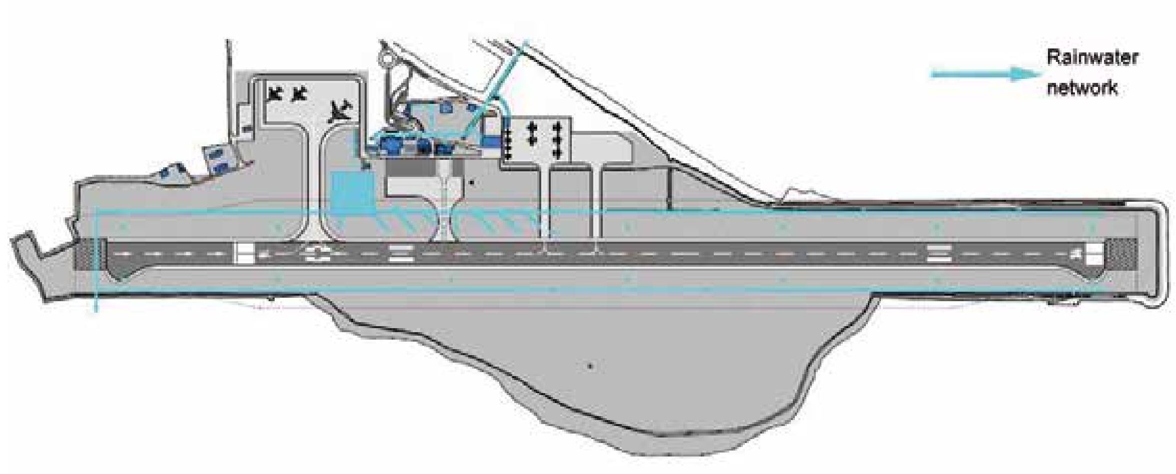
Dzaoudzi Airport (Mayotte): Drainage channel grate

Longitudinal «Satujo» type slot gutter

Retention basin at Angers-Marce Airport

Photographs from the: Water and Environment / 2000 STBA report

Example: Mayotte Airport, diagram of stormwater treatment system.



Mayotte airport extension plan. Runway. (Direction de l’Equipment de Mayotte - ADPi and Mediterranean CETE, Sogreah)

Huahine Airport, French Polynesia. Photo © Rennboot / de.wikipedia

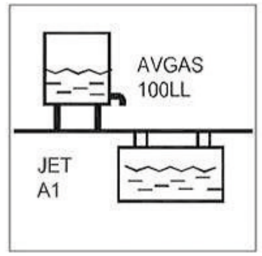
Maintenance operations and runway rehabilitation can also cause pollution (rubber removal, preparing and laying a new layer of asphalt). The main pollutants that affect the soil, water and consequently natural sensitive areas are:

- aircraft and aircraft service vehicles, ground equipment for handling hydrocarbons and reactor combustion products. Multiple sources of pollution are linked to servicing, storage and distribution;
- trace metals and heavy metals (lead, copper, zinc, cadmium, chrome, etc.) are the main causes of pollution resulting from transportation (trucks, tractors, small trucks, mobile units, etc.) on the runways, or parking lots for machinery and assistance vehicles);
- oils, greases, solvents, special liquids used for maintenance (maintenance of aircraft, vehicles and assistance machinery);
- fire prevention products;
- other pollutants linked to airport operations (rubber tyre marks, brake lining residues, products for the coinstruction or rehabilitation or construction of runways and taxiways (concrete or tar based binders, solvents, resins, ...);
- products for managing green spaces (pesticides, fungicides, rodenticides, ...).

Usually, pollution is due to technical or human failures (extreme weather can worsen the phenomena)

SOIL POLLUTANTS
IN HYDROCARBON ZONES

Supplying the depot



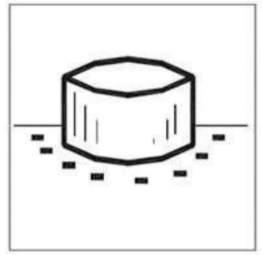
Storage (depot)

Servicing (refuelling)

Airports store not only hydrocarbons but also petrol and diesel for service and ground handling vehicles.

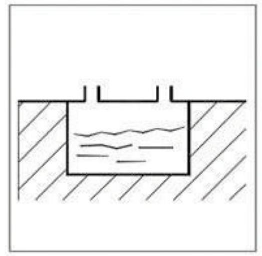
High risk of pollution in servicing, storage, and distribution areas.

(extracted from the of the TCAS report: «Technical Note on the issue of airport soil pollution, 2007»)



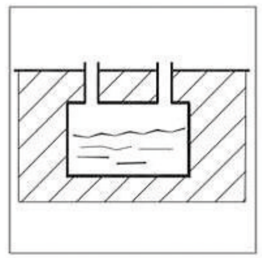
Aviation reservoir

Hydrant system

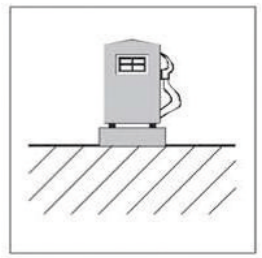


Semi-underground reservoir

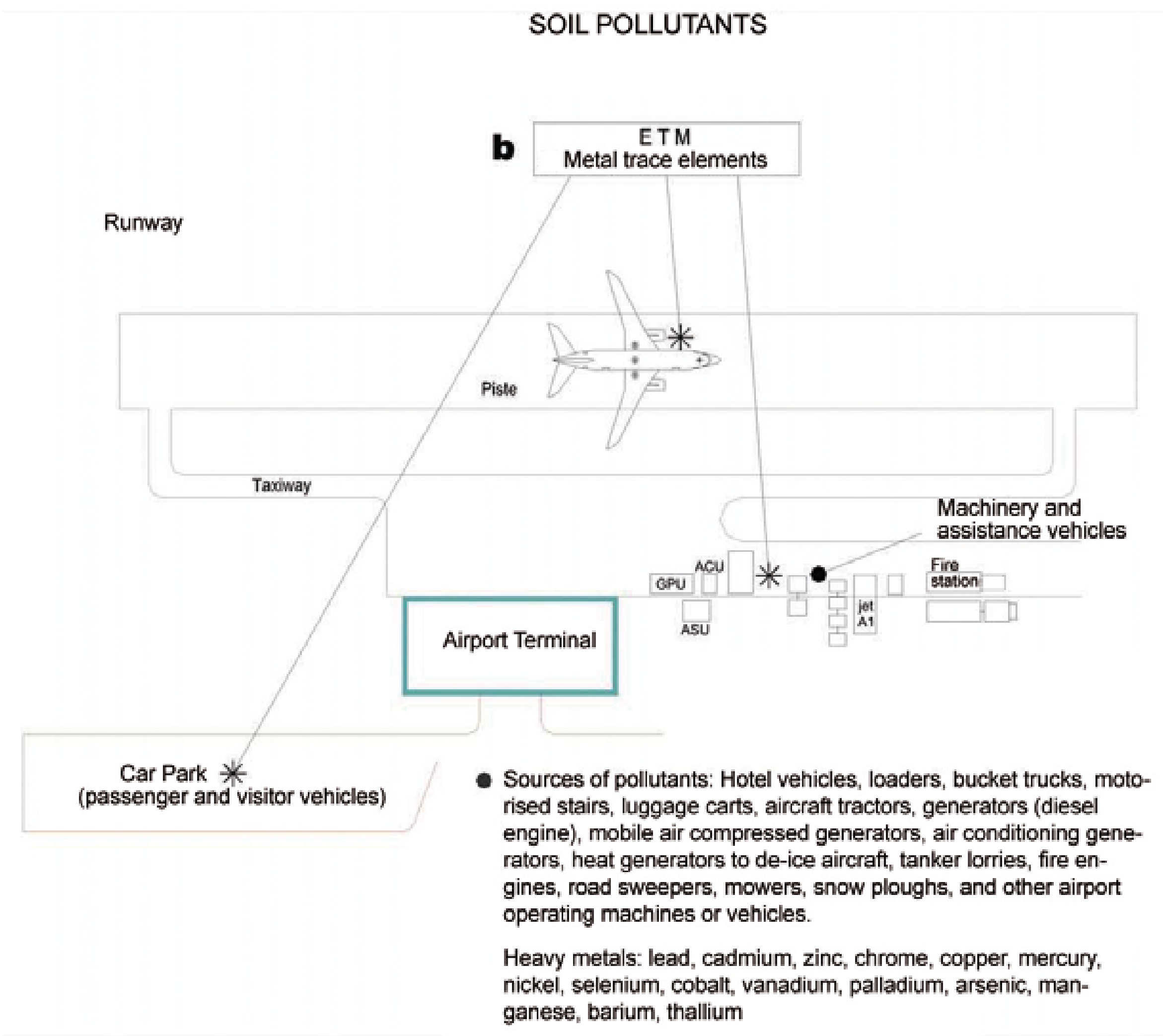
Lorry tanker



Underground reservoir



Fuel pump



Soil pollution in aeronautical platforms (extracted from the of the TCAS report: «Technical Note on the issue of airport soil pollution, 2007»)

3.1.3. AIRPORT INFRASTRUCTURE IN FRENCH OVERSEAS TERRITORIES

The simplified list of airport infrastructure below shows that most are located at low altitudes, particularly in French Polynesia:

Overseas Territories	Airports / airfields	Z ≤ 5m	Geomorphologic location and environmental pressures: * = Low, ** = average, *** = high
Guadeloupe	1 airport 2 airfields	1	Mangroves and near reefs *** Coastal Plain
Saint Barthélémy	1 airfield	0	Coastal Plain *
Marie-Galante	1 airfield	1	Coastal Plain *
La Désirade	1 airfield	1	Coastal Plain *
Saintes	1 airfield	0	Coastal Plain *
Martinique	1 airport	1	Mangrove ***
Saint Martin	1 airfield	1	Coastal Plain and bordering lagoon *
Guyana	1 airport 7 airfields	1 1	Bordering mangrove ** Inland
Reunion island	1 airport 2 airfields	0	Coastal Plain *
Mayotte	1 airport	1	Bordering barrier reef flat***
Eparses Islands, Europa, Tromelin, Juan de Nova, Glorieuse	1 airfield 1 airfield 1 airfield 1 airfield	1 1 1 1	On coral island *** On coral island *** On coral island *** On coral island ***
French Polynesia	1 airport 47 airfields	1 43	The majority on fringing reef flats or barrier reefs ***
New Caledonia	1 airport 14 airfields	1 4	In mangroves and coastal wetlands *** Most on plains and plateau*
Wallis & Futuna	1 airport 1 airfield	0 1	On a plateau Coastline with marine embankment ***

Table 4: Airports in overseas territories and their geomorphologic location.

A complete table of airports can be found in the appendix.

3.1.4. POSSIBLE IMPACTS OF CLIMATE CHANGE

VULNERABILITY TO CYCLONIC SURGES AND RISING SEA LEVEL

A number of airports in French overseas territories are located either on a plateau or coastal plain exposed to sea, where there are no coral reefs. This is the case in Reunion Island, Guyana and some airfields in New Caledonia. These airports are not concerned by this guide.

However, airports where infrastructure was built for technical, functional and geomorphic reasons and that are concerned, are those in:

- coastal plains near mangroves or in mangroves (in Martinique and Guadeloupe for example);
- or near coral reefs and even on them, as is the case in Mayotte and French Polynesia.

These facilities are directly concerned by the possible effects of global warming because they are located at low altitude (usually between 1 and 5 m asl and are thus vulnerable to cyclonic surges and rising sea level.

Damage to these infrastructures could then have a direct negative impact on the most sensitive areas in the vicinity, i.e., coral reefs and mangroves.

Major impacts would result from a combination of the following conditions:

- intensification of cyclones in all tropical regions, with stronger maximum wind speeds and higher occasional rainfall;
- and rising sea level.

The resulted of these combined effects is that the soil tends to subside under the weight.

These phenomena are likely to be very violent, primarily concerning runways located on atolls, but also those located in coastal areas on high mountainous islands, i.e. those that have a high watershed due to steep slopes.

In the cyclone season, when very strong swells occur (and the sea level rises due to the barometric depression) and occasional heavy rains, airport infrastructure can become submersed and flooded with terrigenous particles originating in the watershed upstream. These floods may be extensive and prolonged, in addition to which, the high sea level during the period of extreme weather will slow down drainage from the watershed to the sea.

The damage will affect:

- the protective structures of runways and taxiways (main armour layers made of riprap) by potentially weakening or partially destroying them. In French Polynesia, a large number of runways are built on reef flats at around 2 meters above the average sea level, the outer layer of rocks on the protective structures can be dragged over the reef flats by the increased swell, and cause functional destruction of coral reefs. Similarly, the core materials of the defence structures can be dispersed over the reef flats and asphyxiate coral formations.
- buildings and infrastructure which may release pollutants (particularly hydrocarbons: storage, depots and tanks);
- the runway drainage system, if the airport has been submersed by the sea and floods. Drains can be blocked by marine sediments projected by the waves onto the runways and terrigenous particles originating from overflowing rivers in the watershed and possibly from settling basins and flow control systems upstream from the airport;
- pollutants may be released from the retention basins that are part of the airport's sanitation system;
- runways and parking lots that could leach after submersion, dispersing rubber and other traces of pollutants into the reef environments;
- runway coatings (outer asphalt layer); roadway surfaces (crushed stone layers in particular) which can lead to dispersal of these materials (which may be pollutants) and cause localised hyper-sedimentation in reef formations.

Example of coral blocks that have been pulled off and dragged onto a reef flat during a cyclone (photo: Samuel Etienne)

VULNERABILITY DUE TO HIGHER TEMPERATURES AND INCREASING RAINFALL

The possible increase in rainfall (outside the cyclone season) will vary depending on each tropical region, like the expected increase in temperature.

Droughts or a general increase in rainfall could affect the durability of the runway and its structure. The impact would not only be on its surface, but also on the soil due to a possible rise in the water table, which can increase pore pressure on base layers and on the foundation of the runway, thereby altering its structure.

At some sites, increased rainfall could create or extend wetlands close to runways, which, in turn, will attract more birds to the area and increase avian risks during takeoff and landing.

While on the subject of higher temperatures, it will be advisable to check if the forecast increase in temperature could affect the durability or the structure of the surface of the runway.

Depending on the answers to these questions, runway maintenance and the management of the areas in their vicinity could need to be reviewed, and the necessary adjustments made to the technical design of future runways.

Flooded airport and debris: Faa'a Airport, Tahiti. (Tahiti Herald Tribune-March 2010)

3.1.5. TECHNICAL RECOMMENDATIONS FOR ADAPTATION

Given the above remarks, we recommend a diagnostic survey by the appropriate authorities of the airport infrastructure located on or near coral reefs or mangroves, followed by technical adaptation to climate change, if necessary.

DIAGNOSTIC SURVEY OF EXISTING INFRASTRUCTURE

Should include:

- the geomorphologic location of the infrastructure with respect to coral or mangrove ecosystems and a general summary of the context in the area, including the watershed, existing hydro-geological and hydraulic management and current and potential pressure on the site, including;

- the geometric characteristics of the runway (longitudinal and transversal profiles and altitude);
- all the other characteristics of each structure, in particular those likely to be a source of pollution (depots, reservoirs, etc.);
- characteristics of the drainage and sanitation systems of runways and parking lots;
- a summary of the structures' management protocols and incidents, especially during exceptional weather conditions and any measures taken;
- an analysis of current and potential problems in the design of the different structures;
- a summary of potential projects to repair the different structures, build runway extensions or new airport infrastructure.

POSSIBLE CONSEQUENCES OF CLIMATE CHANGE FOR THE DESIGN OF ADAPTATION MEASURES, FOR THE MANAGEMENT OF EXISTING STRUCTURES OR THE CONSTRUCTION OF NEW INFRASTRUCTURE

ANALYSIS OF EXTERNAL PRESSURES ON AIRPORT INFRASTRUCTURE

The pressures are mainly linked to the watershed. The risks are more frequent periods of heavy rain, resulting in increased river flows and runoff which, in turn, lead to more flooding and terrigenous deposits in coastal plains.

The following issues must be addressed:

- Can the design of current water management structures in the area cope with foreseeable climate changes?
- Should the flood risk management plans (FRMP) be revised and drainage systems and settling basins upstream from the airport be adapted?

When considering plans for the area,future development projects and their possible impacts on the watershed,must be taken into account by including pressure due to climate change. This should be done in collaboration with the appropriate state and local services.

ANALYSIS OF PRESSURES ON AIRPORT INFRASTRUCTURE

The following questions should be addressed :

- Will existing protection of runway and airport facilities against the sea (embankments, riprap armour layers and end of runway wing walls) cope with future pressures from cyclones and rising sea level? Should they be reinforced? If yes, what type of additional protective structures should be built; will it be necessary to be move or abandon certain runways and infrastructure in very exposed sites?
- Are the runways and their structures (surface layer and wearing course) able to withstand future pressures (higher temperatures, increased intensity of cyclones, occasional heavy rains, flooding and in some areas, drought);
- Are the drainage systems of the runways and parking lots designed to withstand future pressures, or should they be adapted, reinforced, enlarged (review drain diamaters, flow retention basins, hydrocarbon separators, etc.);
- Are the hydrocarbon storage facilities and reservoirs designed to withstand the foreseeable intensification of cyclones and flood risks? The same applies to aircraft and assistance machinery maintenance areas where polluting products are stored.
- Will the specifications in the maintenance procedures for the runway drainage systems have to be revised?

FURTHER RESEARCH WILL BE REQUIRED ON CERTAIN ISSUES

The answers to a number of questions listed above will probably require the following:

- applied research, in particular on runway surfaces (choice of materials, composition and surface layer geometry) or the resistance of certain structures (hydrocarbon reservoirs, etc.), or even the drainage system;
- additional studies to optimise models of local climate phenomena, to simulate extreme hydraulic situations around and on the infrastructure (hydrology and hydrogeology, calculating the risk of watershed floods and overtopping); calculating possible swells in the vicinity of structures and optimising measures to be taken in the design of future protection infrastructure;
- optimising observational systems linked to climate change phenomena near the facilities (possibly additional measuring equipment in weather stations on site, tide gauges);
- research on optimising the design of future runways in coastal areas or in reef environments;
- taking the possible increase in avian risks into account: changes in certain species and increased migration, some species will be attracted to expanding wetlands near runways.

The above recommendations are in «checklist» format to enable diagnosticians to draft a coherent final document for all airport sites (see tables in the appendix).

3.2. PORT INFRASTRUCTURE

3.2.1. SUMMARY OF PORT INFRASTRUCTURE

Another kind of port is located on a river, which is intended to serve boats. A port can perform several functions: provide shelter for vessels, especially during loading and unloading and facilitate refuelling and maintenance.

Anchorages and harbours are generally located in bays protected from prevailing winds and waves. A port will be protected by one or more dykes or breakwaters. A port can consist of several docks, dry docks or floating docks. A port is equipped with piers, wharves, and pontoons and must have access to the sea; dredging may be required to maintain the neccessary depth in the access channel. A port has to be connected to other means of transport by road, rail and canal. Ports come in all sizes and serve just a few boats to thousands of vessels. Ports may also contain commercial or industrial buildings and may have different missions: trade, fishing, tourism, or military. Ports play a strategic, economic and military role and many combine several activities, which are often separated geographically, for example, by different basins.

Port facilities include basins of adequate depth, lined by docks that usually have defences and secure embankments, handling equipment (cranes, etc.), bunkering positions and a fresh water supply, jetties and breakwaters. The access channel has signage. Ports have embankments on the land side.

Commercial ports serve commercial ships, passenger ferries and cruise ships as well as deep water vessls, including cargo ships transporting goods, large vessels particularly oil and ore carriers, but also container ships, and freighters.

Goods may be liquid (oil and chemical tankers) and require dedicated tanks and pipes; in bulk (bulk carriers requiring silos or storage space) - or packed, i.e mixed cargo requiring warehouses and cranes; or container ships with associated large storage spaces. Rolling cargoe (for ro-ro ships) need waiting areas, and maybe even parking zones.

Docks and ports for hydrocarbons: these docks are designed for oil and gas (methane, butane and propane) tankers. They are often in the immediate vicinity of the corresponding storage facilities.
At some sites, unloading is done through pipes called «sea-lines» usually because there is a lack of space and/or high investment costs for building a terminal; in this case, the ship is moored on «dolphins» or anchored.

These sites are particularly dangerous because of the risk of explosion, fire and pollution by leaking products, and when tanks are emptied. They are classified as «ICPE» (Environmentally Protected Facility) and «Seveso». The port of Papeete in Tahiti is a special case: all the fuel and gas facilities were built on the harbour wall, right in the axis of the runway of Faa'a international airport; it is therefore a major risk for the population and all the surrounding coral reefs.

Fishing ports are the most widespread, and are often smaller than other types of port. Their size varies depending on the boats they serve: deep sea trawlers which remain at sea for several weeks require more dock space to unload their cargo than small day fishing boats which have to unload quickly. Infrastructure in fishing ports is simple: quays and/or pontoons, a fuelling and refuelling station, and an ice machine.

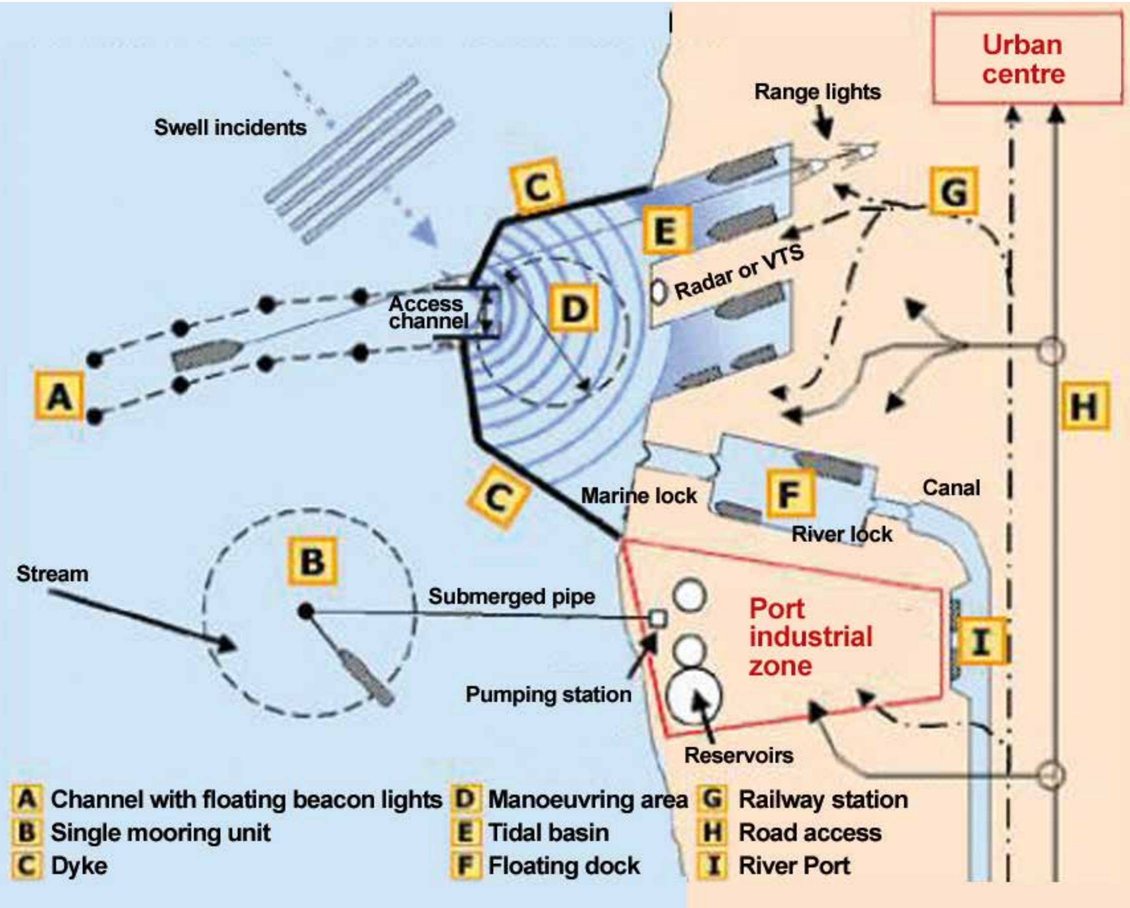
Leisure ports and/or marinas serve sailing or motor boats for either recreational purposes or regattas. Most boats are small (less than 20 m long) and berths are standardised via pontoons and «cat-ways.» There is a harbour master's office and different types of services are available: refuelling, dry commissioning and maintenance, a fuel pump, and various services for crews.

Military ports (or naval bases) serve warships.

The geographic position and the geometry of the docks and piers determine a port's qualities and have an influence on the following parameters:

Protection

A pier or breakwater in a port can provide natural or artificial protection. The port's geometry and its water masses are not the only factors that influence waves. The size and speed of the vessels (depending on the time the tide comes in) also have an impact on waves and their action.



Schematic diagram of a seaport. Source: www.cours-genie-civil.com

Example of a multifunctional port: the port of Papeete. Photo: C. Blondy, 2005 satellite image; Google Earth, 2009.

Depth

The available depth, which depends on the tides, determines the size of boats that can enter based on their draft. In the case of large ports, depth is maintained by regular dredging of the bottom and/or access channels. A ship's draft is influenced by the sinking phenomenon caused by the harbour, channels and docks' geometry, but also by the size and speed of ships which affect the waves and their action, which in turn, also depend on the tides.

Signage

Different kinds of signs are used in the marine zone including beacons, floating buoys at sea or fixed on shore to signal dangers for ships and to show the layout of the port's access channels and shelters. These signs can be buoys, masonry turrets or poles and spars.

There are two types of signage on:

- moorings;
- masts fixed to rocks or flats.

While on the subject of buoys, precautions are necessary when moorings set up, but in fact, it is easy to cope with the rising sea level by lengthening the chain to the mooring. However access to fixed moorings often disturbs corals because they are sealed; so to counteract the rising sea level a further disruption will be required to raise it.

A port's entrance must be visible by day and night and possible to locate by non-visual means when there is fog (radar, fog horns, etc.). Signage is based on natural landmarks, mooring buoys or beacons using lateral or cardinal lights and lighthouse system.

Port services

Marine piloting, towing, mooring, providing berths or anchorage, fuelling, safety.

Goods

Handling, storage, security/guarding, and pre and post-shipment.

Passengers

Ferry terminals, shopping centres, walkways, parking lots.

An average sized port also has a number of service vessels of its own, these are not part of the port's traffic, but are used for different port operations.

- Different kinds of dredgers depending on the depth and coverage. The extracted materials are transported by barge.
- Pilot boats to bring pilots on board commercial vessels arriving in the port.
- Harbour tugs used to help large ships manoeuvre during mooring and turning operations.
- Mooring boats used to bring the mooring ropes to land.
- Refuelling boats: oil tankers to fill tanks, and several refuelling barges when refuelling is not done ashore. Lighters are used to transport goods from the dock to the ship, but in fact are rarely used.
- Security vessels: fireboats in case of fire, rescue canoes for sea rescues, patrol boats, pilot boats, and port authority vessels.

IMPACTS OF PORT INFRASTRUCTURE ON THE NATURAL ENVIRONMENT

Naturally the construction of a port and its access roads and shipping channels will have an impact on the environment, as will the port when it is funtciong, these impacts are:

on protection structures:

- changes in the hydrodynamics and sediments around the structures and in the navigational channels to that lead into the port can cause erosion at the base of the structure and/or hyper-sedimentation, which alters the local ecosystems (erosion leads to degradation of the coral reef, while hyper-sedimentation results in asphyxiation of seagrass meadows);
- positive effects: protection structures made of rockfill or concrete blocks form a new hard substrate for new species to fix onto, like coral, thereby creating an artificial reef (many species like the shelter provided by the cavities in the blocks).

on port basins, docks, technical zones and warehouses where polluting products used for port activites are stored:

- hydrocarbons, used oil, heavy metals (chronic pollution: bilge waters, exhaust fumes, and accidental pollution by hydrocarbon spills at fuelling stations or depots where drainage oil is stored;
- detergents (surfactants and phosphate compounds) in grey waters, left over after boat washing. Detergents cause eutrophication and can significantly degrade marine flora and fauna;
- wastewater (at mooring units) causes bacteriological pollution, deposits of nitrate and phosphates which cause eutrophication;
- stormwater (runoff from parking lots, container storage areas): hydrocarbons, deposits of metals and toxic products, floating and underwater marine litter;
- antifouling paints (containing toxic copper oxide), which affect marine fauna and flora,
- aluminium and zinc salt from anodes used to prevent corrosion of the hull (which are toxic for marine fauna and flora);
- spills of toxic products (commercial ports);
- sediment resuspension in port basins when large vessels manoeuver, dredging basins, or navigation channels. These sediments may be loaded with toxic products (in particular heavy metals) and pollute sensitive natural areas near the port or asphyxiate them by hyper-sedimentation.

Furthermore, port infrastructure is often located at the mouths of rivers, streams or downstream from valleys and ditches, in which case port basins are an outlet for stormwater loaded with suspended solids, various pollutants and macro-waste.

It should be noted that most risks of pollution listed above has to be part an integral of port management (stormwater and wastewater purification systems), macro-waste management, through planned actions in the case of accidental pollution by hydrocarbons or toxic products in port basins).

For more details on port pollution, its management and impact on the natural environment, please refer to documents cited in the list of references in the appendix.

3.2.2. PORT INFRASTRUCTURE IN FRENCH OVERSEAS TERRITORIES

The number and type of port structures vary considerably from one overseas territory to another depending on the size of the population, the coastal geomorphology and economic activities.

The port descriptions below were selected in view of their activity and size.

Type 1
Large ports: commercial ports and naval bases

These ports have major protective structures (anti¬swell walls that are several meters high, protections with very large riprap blocks or concrete blocks several cubic metres in size weighing from 1 ton to dozens of tons.
Commercial actvitiy and the size of the manoeuvring vessels can be a source of chronic pollution, especially due to accidents.
The February 2012 Reform Law on ports in the overseas territories' ports was published in October, 2012 and included five decrees. Since the 1st January 2013, France has built four new major sea ports in overseas territories. These new public ports replace the independent port of Guadeloupe, and three French ports of national interest previously run by local Chambers of commerce and industry, at Fort-de-France (Martinique), Degrade-des-Cannes (Guyana) and Le Port (Reunion Island).

Type 2
Medium to small ports: these comprise small fishing ports and marinas; small ore docks (New Caledonia) and various docks and small wharfs

These ports are very common. They are protected by medium-sized riprap weighing several hundred kilos to 2-3 tons or by medium to low vertical or inclined walls.

They are a source of pollution because unfortunately users often do not comply with regulations concerning pollutants and waste management. Boat maintenance and bunkering can be a source of mainly accidental pollution.

Below we give give an overview of the type and size of port infrastructure in each overseas territory. For a complete list of infrastructures and the type of protection, see the appendix.

REUNION ISLAND

LARGE PORTS

These are the industrial port of Le Port de la Pointe des Galets, Port of Saint Gilles and the port of Sainte Marie (on the end of Gillot airport's runway).

Reunion's industrial port © Marie-Annick Lamy-Giner June 9, 2006

The port of Saint Gilles © Hotel-les-creoles.com

MEDIUM-SIZED STRUCTURES

Small fishing ports and marinas (in Saint Leu and Saint Pierre on the west and southwest coast in a reef environment, and ports in Sainte Rose and Sainte Marie on the east coastn which is exposed to the sea).

Port of Saint-Leu on a reef flat, © Sea Seek.com

Port of Saint Pierre adjoining the reef flat (Photo: Sea-Seek Nautical Guide)

MAYOTTE

MAJOR STRUCTURES

The commercial port of Longoni.

Longoni port. © Google.

The new port was commissioned in 1992. It is located on the north coast of Grande-Terre on a rocky outcrop and partly on a fringing reef and small mangrove. It has a gas terminal and a dock for tankers.

MEDIUM-SIZED STRUCTURES

Dzaoudzi port (a former commercial port, currently mainly used for cruise ships) and the port of Mamoudzou with a dock for the ferry linking Grande-Terre and Petit-Terre islands.

EPARSES ISLANDS

No port facilities.

GUADELOUPE

MAJOR STRUCTURES

TPoint a Pitre port and ferry terminal, the industrial port zone of Jarry Baie Malhault (deep water port) and a dock at Basse Terre port. A major project to expand Pointe a Pitre port is under study.

MEDIUM-SIZED STRUCTURES

There are dozens around the island and on its dependencies). The facilities are mainly fishing ports and marinas, some moorings with a dock protected by riprap and some small commercial ports in its dependencies.

The biggest of these structures are the marinas in St. Francis, Bas du Fort in Pointe a Pitre, and Rivere Sense on the southern tip of Basse Terre.

SAINT-MARTIN

The commercial port at Gallisbay and four large marinas.

SAINT-BARTHÉLÉMY

The port of Gustavia.

SAINTES

Three small ports.

MARIE GALANTE

Three small ports.

DESIRADE

The port of Beau Sejour (a fishing port and marina on a reef flat);

MARTINIQUE

MAJOR STRUCTURES

The industrial port of Fort de France located in a mangrove environment.

MEDIUM-SIZED STRUCTURES

They are dozens of ports or marinas.

GUYANA

MAJOR STRUCTURES

Sea ports:

- Degrad des Cannes port, near Cayenne, on the River Mahury estuary consisting of one container terminal with three berths measuring 500 m in length, one oil terminal, one ore terminal and one ro-ro terminal;
- Kourou - Pariacabo port serving the Space centre, it is located on the Kourou river estuary and consiss of one ro-ro terminal and jetty gangways;
- the Larivot fishing port located on the River Cayenne estuary.

There is a river port in Saint Laurent du Maroni with a 100 m long dock and the port of Cayenne, on the Guyana river, mainly used by artisanal fisheries.

All these ports are located in a mangrove environment.

FRENCH POLYNESIA

MAJOR STRUCTURES

The port of Papeete and Faratea on the Taravao peninsula (second industrial port in French Polynesia).

MEDIUM-SIZED STRUCTURES

There are many medium and small ports or commercial docks and small fishing ports and marinas.

LEEWARD ISLANDS

Tahiti
Seven marinas and fishing ports, the largest marina is Tania Marina, located at Punaauia near Papeete.

Moorea
The port of Vaiare with a dock for ferries, a marina and a small fishing port in Papetoai.

Raiatea
The port of Uturoa, three large marinas and two small docks in a reef environment. The layout of the cruise ship dock and ferry terminal has meant that the whole former port area and Uturoa market had to be restructured.

Tahaa
A marina (closed).

Bora Bora
The airport dock on the barrier reef and Vaitape port on the high island and a small marina.

Huahine
Fare port and five small marina type developments and fishing ports.

View of Uturoa and its marina, in the background the airport runway on the reef flat, © Sea Seek.com

TUAMOTU ARCHIPELAGO

There are limited facilities with small docks at **Tikehau, Apataki, Ahe, Manihi, Fakarava, Kanehi,** and **Raraka. Rangiroa** has two small ports in Avatolu and Tiputa, a marina in Tiputa and a dock at Hohotu. Hao: the former naval base has many fuel depot terminals. The site is being redeveloped. **Moruroa:** a big old naval base.

GAMBIER ARCHIPELAGO

A port both in Manga and Totogegie.

AUSTRAL ARCHIPELAGO

A dock in Rimatara and two in Rurutu: Morerai port and a marina in Tubuai.

MARQUESAS ISLANDS

The biggest facilities are Atuona port on the island of Hivaoa (a dock with a large wharf which can serve freighters), NukuHiva and Ua Pou. There are a dozen other docks and small wharfs, sometimes protected by a small dyke.

NEW CALEDONIA

MAJOR STRUCTURES

- Noumea port, which is made up of several sites:
  - an ore zone, near the Le Nickel factory;
  - commercial zone: containers, vehicles, bulk carriers;
  - fishing zone with associated services and processing facilities ;
  - hydrocarbon zone;
  - three main zones for leisure boats.

Noumea port (source: vinci.com)

The construction of a coal power plant for the Nickel Company (SLN) will require a specialised dock.

- a new nickel ore processing plant in the south, at the Bay of Prony, required a new port zone for incoming supplies and outgoing products;
- similarly, in the Northern Province, the new Vavouto factory in Voh required an ore dock and an oil terminal, which is supplied by sea lines.

Access to this site is by a channel dredged in the lagoon itself.

MEDIUM-SIZED STRUCTURES

ON GRANDE TERRE

These are the most common and frequent type of structure in New Caledonia. However, their density is low compared to the length of New Caledonia's coastline, except in the Noumea urban area. The structures are marinas, small fishing ports and ore docks. There are about ten of them and, other than the port of Noumea, the biggest are the ore ports of Nepoui, Thio and Prony, which have pontoons, conveyors and large embankment surface areas.

Nepoui ore port (New Caledonia) (by Hockers 19)

ON LOYALTY ISLANDS

Mare
Tadine Port.

Lifou
Wé port, a pontoon and wharf.

PINE ISLANDS
Kuto Pier.

WALLIS & FUTUNA

WALLIS

Wallis has the following medium-sized structures:

- Mata-Utu Quay, on reef flats, serving 90 m ships, accessed by a natural channel and recently enlarged embankments;
- Halalo Dyke: a structure with a ramp access, originally built for landing crafts (US Navy 1943), it has been transformed into an oil terminal;
- a fishing port project is underway.

FUTUNA

A timber pile wharf with a metal structure at Laeva.

The table opposite lists the numbers of ports in French overseas territories and their size, and location with respect to coral reefs and related ecosystems.

LIGHTHOUSES AND BEACONS

All the lighthouses at Venus Point in Tahiti, Enfant Perdu in Guyana, Fakarava in French Polynesia, and Amedee in New Caledonia, are located on coral islets.

3.2.3. POSSIBLE IMPACTS OF CLIMATE CHANGE

The direct impact of increases in temperature and/or droughts will be slight on this type of infrastructure.

However, the impacts of more intense storms (especially during the cyclone season) and a rise in sea level will lead to more frequent overtopping of defence structures thereby putting them at risk of deterioration, especially riprap structures or concrete blocks. Riprap or concrete blocks removed by string swells and dragged across the reef flats can destroy corals and seagrass meadows. The smaller particles in the dyke's core can also smother the reef flats and seagrass meadows and asphyxiate them.

In addition, increased overtopping will have a direct impact on the boats moored in the basin and could destroy them, which in turn,could mean the hydrocarbons, oil and toxic products on board these boats are discharged into the marine environment.

Increased overtopping will also affect embankments on which various port activities take place: aside from a destructive effect it can lead to cause leaching in the facilities and parking lots and the release of pollutants (from the careening area, maintenance workshop for vehicles and handling machines, refuelling equipment, pipelines, etc.) and the dispersal of macro-waste.

The combination of strong swells and heavy rains will increase the risk of flooding of the embankments and of their operations. Under flood conditions, it is difficult for the water to evacuate seawards due to the cumulative effect of a rise in sea level due to climate change and low pressure (the hydraulic slope of the stormwater drains running into the basins will be inadequate and drainage structures undersized).

The frequency of heavy rains will increase pollution in harbour basins that receive the outflow from upstream ditches, valleys or rivers. The pollutants then enter the marine environment along with macro-waste, suspended solids, and various pollutants from soil leaching or overflowing sewage treatment plants or stormwater retention basins located upstream.

Port sites are usually exposed to a sea by the sea, which is why they are protected by special structures: natural and artificial riprap, groynes and dykes. These structures will come under increasing pressure under predicted climate change (see Chapter ?).

Under these circumstances, port sites will have other specific problems:

- If water levels rise, the current height of quaysides may be too low; elevating them is a complex operation and each case will have to be studied in detail;
- all embankments behind the docks are relatively

NUMBER AND SIZE OF STRUCTURES
in coastal areas in French overseas Territories, geomorphologic location and environmental pressures

Overseas Territory	Number of different structures (according to type)	Geomorphologic location	Environmental pressure Zero: 0 - Low * Average: ** - High ***
Reunion Island	Type 1: 3 Type 2: 4	2 exposed to sea 1 reef environment 2 exposed to sea 2 reef environment	0 to * ** 0 to * **
Mayotte	Type 1: 1 Type 2: 2	In mangrove and reef environment In reef environment	** to *** * to **
Eparses Islands: Tromelin, Juan de Nova, Europa, Glorieuse	None	Coral islets	0
Guadeloupe	Type 1: 2 Type 2: > 10	1 in reef and mangrove environment 1 exposed to sea Over half on a fringing reef environment and the others exposed to sea	** to *** * * to **
Saint Martin	Type 2: 5	Lagoon environment, mangroves and reefs	* to **
Saint Barthélémy	Type 2: 1	Reef environment	**
Marie Galante	Type 2: 3	Reef environment	***
Desirade	Type 2: 1	Reef environment	***
Saintes	Type 2: 4	Reef environment	* to **
Martinique	Type 1: 1 Type 2: > 10	Exposed to sea and mangroves Coastal dune areas, seagrass meadows, mangroves, coral reefs	* to ** * to **
Guyana	Type 1: 4 Type 2: 1	Estuaries and mangroves	* to **
French Polynesia	Type 1: 2 Type 2: > 50	Reef flat Reef flat and some sites exposed to sea (Marquesas)	** to *** ** to *** *
New Caledonia, Pine and Loyalty islands	Type 1: 5 Type 2: > 30	Near fringing reefs and mangroves and some sites exposed to sea	* to ***
Wallis and Futuna	Type 2: 3	Near or on fringing reef	* to **

*Table 5: The size of structures in coastal areas of French overseas territories, their geomorphologic location and environmental pressures environmental pressures: zero: 0, low: * average **, high: ***).*

flat, stormwater drainage is via pipe networks with outlets into the sea. Several problems that are specific to these embankment areas should be taken into account:

- if the sea level rises, hydraulic slope of the pipes will be reduced accordingly;
- rainfall may become more violent and evacuation more difficult;
- under a high barometric depression, the water level will risewith a tidal or wind effect on the lagoons. Finally, the waves could overtop wharfs and flood embankments. It is highly probable that these effects will accumulate;

- containers could topple over in high winds during the cyclone season, especially when they are stacked (up to 5 containers when empty, 2 or 3 when full);
- when difficult sea and wind conditions are combined, containers can drift away, leading to a high risk of pollution. Regulations stipulate that empty containers should be cleaned and decontaminated, but this is often done without taking sufficient precautions;
- another risk is linked to the fact that ships need ballast: the main goods route is one-way and cargo ships return lighter. Then when ballast is emptied (except fuel tanks) waters from other seas as well as the living beings they carry (plankton, algae and animals) are discharged without any precautions being taken.

If we refer to the results of a recent SAO POLO study (Adaptation Strategies for sea protection structures or coastal settlements in view of the rising sea level and oceans), the risks linked to the foreseeable increase in overtopping have to be taken very seriously.

In fact, the study cited in Chapter 2 on coastal protection structures, shows that if the sea level rises by 1 metre, exceptional overtopping flow rates could be very close to the annual return rate for 2100. This result raises questions about future level of protection of existing infrastructures'. This problem is critical for port infrastructure as its operational service life is relatively long (40 to 50 years).

Access channels will need more frequent maintenance due to more violent rainfall which results in higher flow rates and rougher waters and stronger currents in the lagoons. Dredging or even expansion is likely to have a strong impact on the neighbouring coral environments and strict precautions should be taken.

3.2.4. TECHNICAL RECOMMENDATIONS FOR ADAPTATION

Given the above mentioned issues, we recommend a the appropriate authorities conduct a diagnostic survey of the port infrastructure located on coral reefs or mangroves, or in their vicinity, and technical measures for adaptation to climate change taken, if necessary.

THE DIAGNOSTICS ON EXISTING INFRASTRUCTURE

Should include:

- the geomorphological location of the infrastructure with respect to coral or mangrove ecosystems and a general summary of the context, of the area including the watershed, the level of hydro¬geological and hydraulic management and identification of current and potential pressures on the site;
- the geometrical characteristics of the protective structures' (peak altitude, cross-section, type of structure, see Chapter 2.4. on protection structures);
- the characteristics of different structures linked to port activities and, particularly those that have specific sources of pollution (toxic substances storage, hydrocarbon reservoirs, fuelling and careening areas, maintenance workshops, parking lots and machinery used in port activities' maintenance areas...);
- the characteristics of warehouse drainage systems, parking lots and specific sanitation systems (oil separators, decanters, etc.);
- a summary of management procedure and previous incidents that affected the structure,

especially during exceptional weather conditions, and the measures taken;

- an analysis of current and potential problems in the design of the different structures;
- a summary of projects to repair structures, extend embankments or construct new infrastructure;
- analysis of risks in the container storage zone. Containers are stacked five high when empty and two or three high when full. Despite being interlocked, severe cyclonic winds can topple them over and move them. This would be even easier when embankments are flooded. Depending on their contents, full containers degrading in warehouse areas, or worse, falling into basins, represent a high risk of pollution to the marine environment. Solutions must be found to avoid these types of risks in the future.

On the subject of reinforcing protection structures or building new ones (see Chapter 2.4.on protection structures)

Here we underline the importance of the SAO POLO Project's findings - Procedure to define a structure's consolidation and adaptation strategy- final report August 2012- IGCC No. 09.000683 Sao Polo – Coordinator Philippe Sergent).

The study highlights the important measures that need to be taken. It shows that structures in shallow water are particularly at risk from flooding (which is the case of most ports in a reef environment). A 1 m increase in the average sea level would mean raising the structures by 1.5 to 2.5 m. to maintain the original level of protection against overtopping, and up to 3m for waterproof structures. This would also require a significant increase in riprap mass (double for a 4 m high structure).

The study also analyses the different consolidation techniques possible for structures, suggests adaptation strategies and provides guidance on further research.

The frequency of monitoring the status of structures and the method for diagnosing them will need reviewing. Here we recommend referring to COTEEF's study on methods of diagnosis. The links are given in Chapter 2.

FURTHER RESEARCH NEEDED ON CERTAIN ISSUES

The answers to some of the above questions will probably require:

- further applied research, particularly on embankment revetments (choice of materials, composition and structure of revetment layers) or the resistance of specific structures' (hydrocarbon tanks);
- additional studies on optimising the models of local climate phenomena, simulating extreme hydraulic situations on and around the infrastructure (hydrology and hydrogeology, calculating the risk of watershed floods and overtopping); calculating possible swells in the vicinity of structures and optimising measures to be taken on defence infrastructures at the design stage;
- optimising observational systems linked to climate change phenomena near the infrastructure (possibly setting up additional measuring equipment in weather stations on site, tide gauges);
- research on optimising the design of future protection structures.

The recommendations above are in «checklist» format to enable the diagnosticians to draft a coherent final document for all port sites, depending on the type of port (commercial, military, fishing, recreational).

3.3. ROAD INFRASTRUCTURE

It is important to note that, within the framework of the NAPCC Transport working group,two documents are currently under validation:

«Action 1: NAPCC infrastructure and transport systems». This report is the result of a study that had three distinct objectives:

- to identify technical documents (repositories, standards, legal texts) that will need to be reviewed to take climate change into account;
- to list the potential impacts of change climate on existing infrastructure and highlight a few points that require particular vigilence;
- to identify climatic parameters to design, operate or maintain transport infrastructure.

The report is divided into four parts. The first summarises the key climate changes expected by 2100, based on reports eby Jean Jouzel (2011 and 2012) and the three others corresponds to the three objectives mentioned above.

«Action 3: Risk analysis methodology on climate change for infrastructure and land, sea and air transportation systems.»

This document provides detailed information on different types of infrastructure and a grid for the evaluation of their vulnerability to climate change. It makes it possible to identify hazards linked to climate change and their potential impacts on different infrastructure and function.

These documents are useful references as are other SETRA reports and guides (in French)available at: http://dtrf.setra.fr

The analysis below focuses on the linear vulnerability of the infrastructure that could have an impact on the natural environment, and is therefore quite different from the NAPCC Transport working group's reports which they cover every other feature of an infrastructure's functionality. The two approaches are complementary and should be taken into account together by operators.

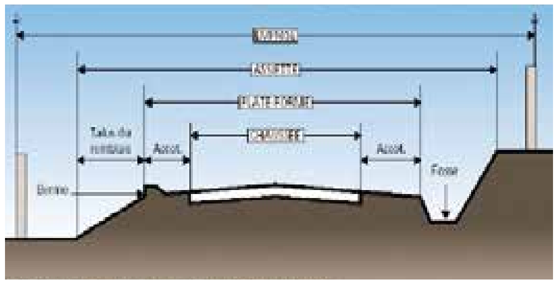
3.3.1 SUMMARY OF ROAD INFRASTRUCTURE

Like airports, road infrastructure will definitely be affected by climate change and could therefore have a direct or indirect impact on the coastal and marine environment. Potential problems not only concern roads that run along the coastline, but also those located in watershed zones, as their degradation could cause pollution to the coastline and the marine environment downstream.

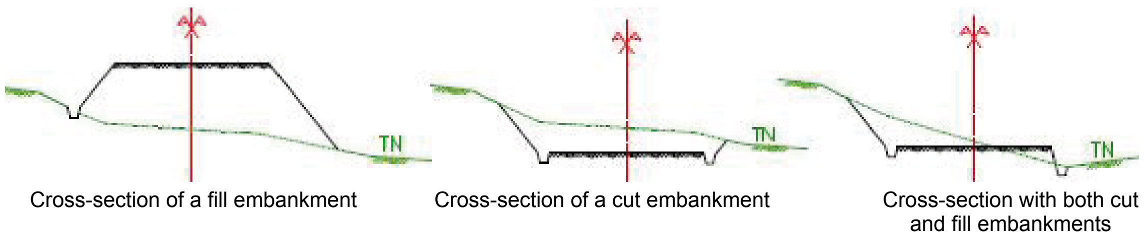
Thoroughfares, roads and streets allow land vehicles to move around. Intercity roads, rural roads, city streets, and forest tracks all have a different administrative status: motorways,, national roads, regional roads, local roads, country and/or rural roads.

Roads usually belong to the public domain, but can also be private used by the public, or not.

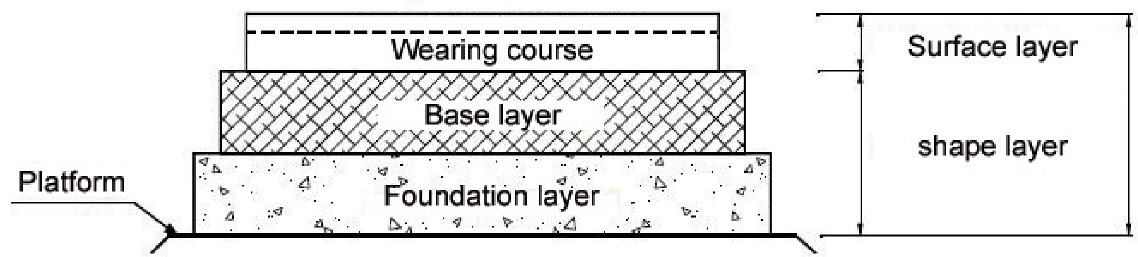
Road authorities control rights of way that include dependent structures, ditches, sanitation pipes, settling-retention basins and the base of the roadway, which is the area between land entrances: sloping fill embankments and ridge cut embankments.



Typical cross-section of a road. Source: fr.slideshare.net



Different types of road profiles. Source: fr.slideshare.net



A road structure (LCPC and SETRA, 1998)

MAIN CHARACTERISTICS OF ROAD INFRASTRUCTURE

Cross sections

Roads at least ten metres wide and motorways and urban expressways can be up to several dozen metres wide.

Cross sections provide the basis for freeing the ground coverage.

Earthmoving operations require cutting and filling as function of the site topography; large scale earth movements can have a major impact on sensitive natural areas.

The type of embankment used must take into account the risk of water infiltrating the road and the ground: the transport of crusher run stone from cuttings or neighbouring areas due to the project's geotechnical pressures, road or demolition waste (with a check for pollutants).

Road crossings

These are bridges, viaducts, tunnels for water, and possibly several other tiered causeways: other roads, pedestrian walkways, train tracks).

Roadways

Can be divided into the following categories:

- dirt roads, tracks;
- paved roads whose structure varies with the type of road (volume of traffic including HGV, ground support, etc.). The road is made up of different layers of materials on top of the ground support (see SETRA catalogue of the different types of road structures):
- subgrade layer: this is the supporting base which may be the ground itself, treated if necessary with lime or cement or with filler materials (untreated crushed stone);
- foundation layer: if the structure includes one (hydrocarbon binder – crushed stone, hydraulic binders - cement - various economic binders, slag, fly ash, lime etc.)
  - base layer: untreated crushed stone or treated with various binders as above,
  - wearing course. This can be made of:
    - concrete or bituminous coatings (hot bitumen blends or cold emulsion and gravel). Special coated moduli use elastomeric bitumens;
    - surface coatings (bitumen layer or bitumen emulsion and gravel bilayers or tri-layers).
- concrete roads (with hydraulic binders), hydraulic structures also use lime and fly ash;
- flexible structures are made of an untreated crushed stone as base layer, topped by a surface coating (bitumen) for the wearing course;
- semi-flexible structuresand made of gravel with a hydraulic binder or bitumen as the base layer with bituminous concrete for the wearing course.

Sewerage facilities are vital; they can be earth ditches, open concrete or slit drains, optionally drains in the pavement, piped duct crossings, retention and/or settling basins. They collect runoff from cut and fill embankments and the roadway; drainage removes water which mayotherwise back up in the embankments and road structure or permeate through the revetment.

Road areas. They include shoulders, cut and fill embankments, recolonised ground coverages, medians, roundabouts, rest and service areas. When these areas have vegetation (green spaces) they are regularly maintained by cutting, slashing, cleaning and chemical treatment. Vertical and horizontal signs ensure road safety, as do various road protection structures (metal or concrete barriers, pedestrian pathways, etc.).

In low-lying road sections, all the road's components are exposed to hazards. Roads are highly exposed in all types of sections: cut and fill embankments, sanitation, road structures, etc.

3.3.2 IMPACTS OF ROAD INFRASTRUCTURE ON THE NATURAL ENVIRONMENT

The construction phase has an obvious impact on the natural environment, but a road in service also generates pollution that could have an impact on soil, vegetation, groundwater tables and particularly sensitive environments in the vicinity (mangroves and coral reefs in inter-tropical zones).

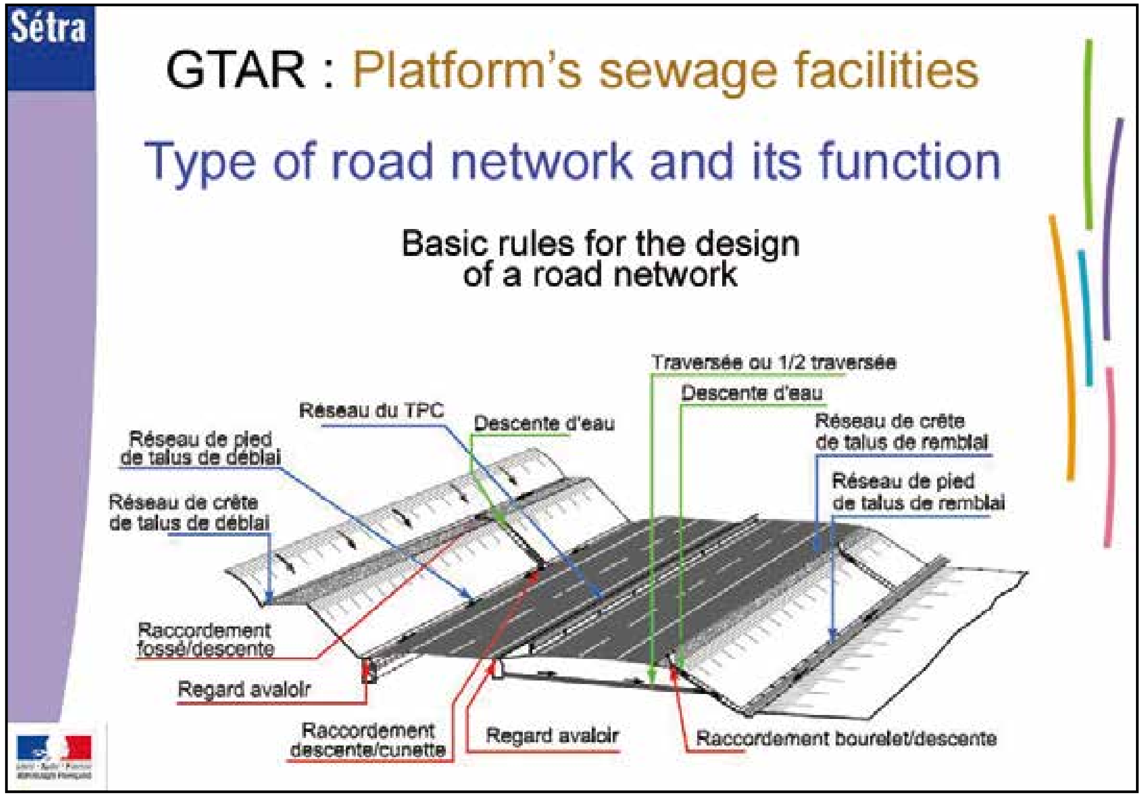
In addition to road pollution from vehicles, there are many other complex direct and indirect impacts. They vary with the context and are either mitigated or amplified depending on how the roadway is positioned, built, managed, maintained, and, of course its secondary impacts. Land fragmentation by roads is one of the leading causes of biodiversity loss.

A significant amount of discharge into the environment occurs. Tetra ethyl lead is prohibited, but leaching of the pavement still occurs due to rainfall: unburned hydrocarbons and oils, fine particles, rubber tyre marks, etc. These discharges are sometimes collected in settling basins, particularly when the road crosses a sensitive environment (drinking water supply catchments). These impacts should be taken into account when building new roads and adapting existing causeways, if possible.

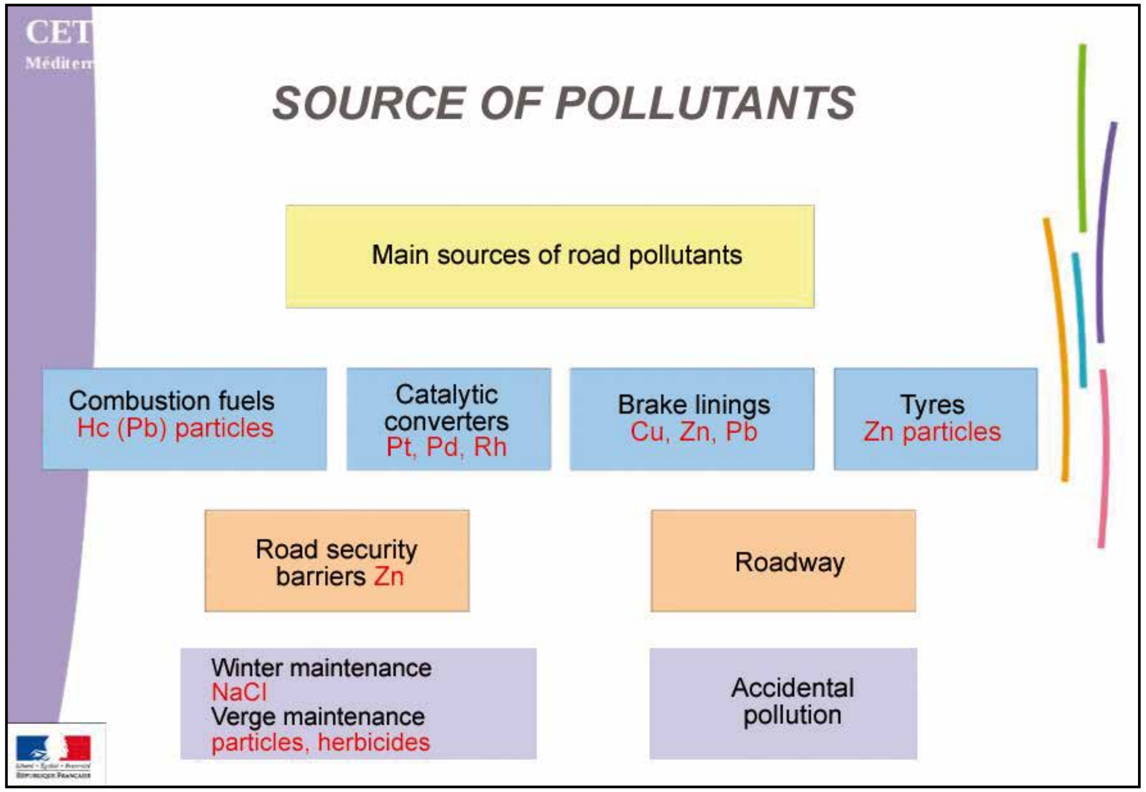
The following impacts should be mentioned:

- **Chronic pollution:** in general this is very low, but likely to accumulate over time. il is due to road traffic (oil, fuel, heavy metals deposited on the road);
- **Pollution linked to managing green spaces:** the use of herbicides, insecticides, fungicides, growth¬limiting products. Compaction by the maintenance machinesand the products used pollute the natural environment by soil infiltration and leaching in sensitive natural areas;
- **Accidental pollution:** this occurs if a road accident involving heavy goods vehicles causing large spills of fuel and/or dangerous materials.

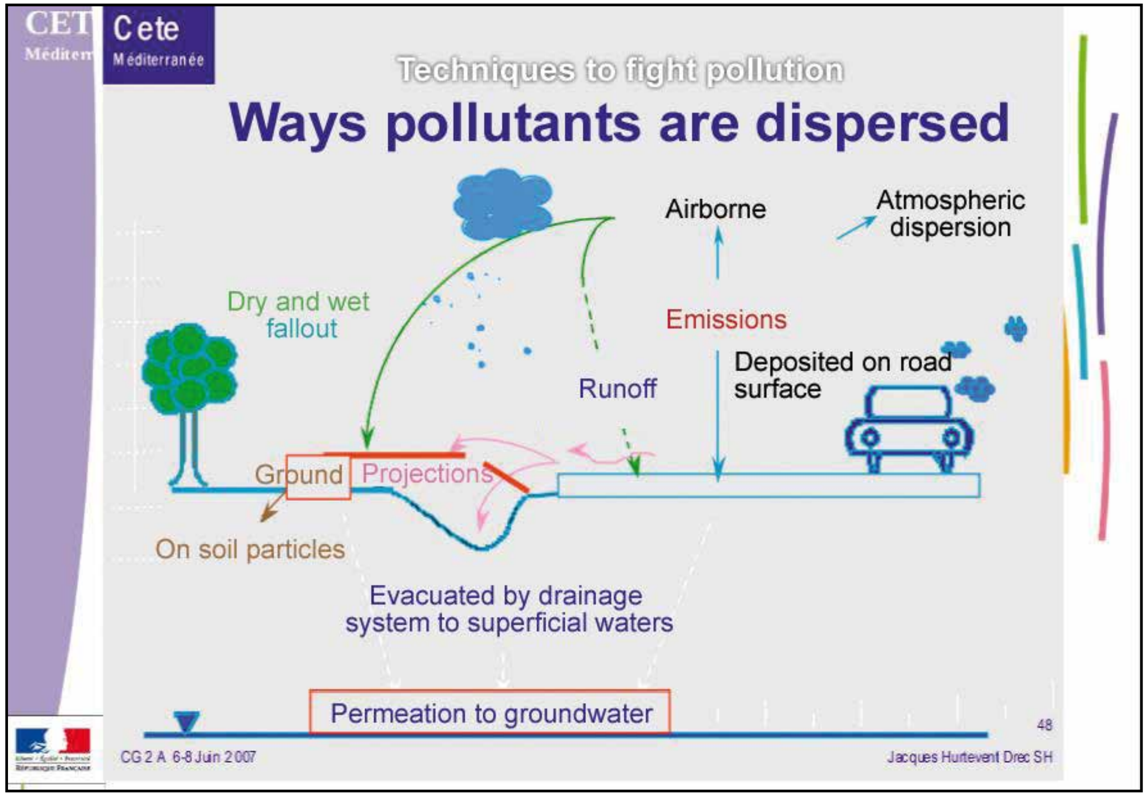
These different types of pollution must be taken into account by the authorities when designing road infrastructure: stormwater and runoff from embankments are collected and directed towards hydrocarbon separators or retention basins that can contain chronic and possibly accidental pollution.



Platform's sewerage facilities (Extracted from SETRA - GTAR Bordeaux on 27/01/09)



Polluants routiers et pollutants and DCE - Annecy October 22, 2010



Source and ways pollutants disperse. (Extracted from CETE – Road pollutants and DCE - Polluants routiers et DCE - Annecy October 22, 2010)

- **Pollution in sensitive environments caused by hyper-sedimentation** during periods of heavy tropical rains or cyclones, for example landslides from cut or fill embankments. The deterioriation of these structuresn can then trigger turbid water plumes and deposits of terrigenous particles in lagoons, which in turn, can damage coral formations and seagrass meadows.

Roadway maintenance and repair can also pollute. This kind of pollution occurs primarily due to technical or human failures or during extreme weather conditions.

3.3.3. ROAD INFRASTRUCTURE IN FRENCH OVERSEAS TERRITORIES

French tropical overseas territories have a toal of around 10,000 km of roads. Each overseas territory's geomorphology and economic development is different, leading to contrasting situations in terms of their surface area, types of roads and traffic.

REUNION ISLAND

Reunion island has over 1,000 km of roads, including 370 km of national roads; most of which run along the coast, and 750 km of regional roads. There are 103 km of 4 lane expressways. On the one hand, the island has recent large scale infrastructure on its slopes: expressways including major structures (viaducts crossing deep gullies, bridges over large rivers with torrential flow rates in cyclone seasons) and on the other hand more traditional roads, including coastal ones.

The New Coastal Road project (in progress) will entail large scale offshore infrastructure with the construction of embankments and viaducts.

Given the economic activity on Reunion Island, there is considerable road traffic plus dense traffic of heavy goods vehicles on its trunk routes, some of which transport hazardous and polluting materials.

Environmental pressures range from low to very high depending on the site and the infrastructure. Natural pressures (risk of landslides, mudslides, massive terrigenous additions in coastal plains) could contribute to degradation of the marine environment. However, the most sensitive areas are coral reefs, which lie along about 20 km of its coastline (in the National Marine Reserve located on the west coast between Cape La Houssaye and Etang-Sale).

GUADELOUPE

Guadeloupe's economic development is similar to that of Reunion Island so it also has expressways with dense traffic (both private cars and heavy goods vehicles). There is an extensive road network with a larger number of side roads than in Reunion Island, for geomorphological reasons. There are 416 km of national roads and 619 km of regional roads and 500 bridges. There are only a few low coastal roads but some go through sensitive areas such as mangroves (Grand Cul de Sac Marin). Extreme weather conditions (especially heavy cyclonic rains) cause considerable flooding of road infrastructure in Pointe a Pitre and destroy bridges and road protection barriers on the coast, particularly on the east Caribbean coast.

SAINT BARTHELEMY, MARIE GALANTE, DOMINICA, DESIRADE

These islands have little road infrastructure and traffic, the environmental impacts are likely to be limited.

SAINT MARTIN

Saint Martin differs from the other small Caribbean islands. It has major sections of coastal roads along low-lying sensitive wetlands; it is divided between two countries (France and the Netherlands). Concerning its geomorphology: Simpson Bay is a large natural pool (a sheltered area during cyclones, suitable for anchorage) which has resulted in considerable development of polluting artisanal activities, especially recreational boat activities. Road traffic is relatively light, but polluting goods are transported by road. However Saint Martin has only 15 km of national roads.

MARTINIQUE

Martinique has a very dense 2,000 km road network: a 7 km motorway through Fort de France, 254 km of national roads, 369 km of regional roads and 1,494 km of local roads. Traffic is congested, especially in the Fort de France region and towards the south (Le Lamentin, Ducos) despite the construction of expressways. Traffic is also congested after Schoelcher in the north along a winding coastal road to Saint Pierre.

Like Guadeloupe, Martinique, suffers from frequent difficult weather conditions during the cyclone season with heavy rains which flood the roads, cause embankments to collapse, landslides and mudslides, cause damage to protection structures along the coastal roads which are already destabilised by strong swells, and damage to other structures.

Compared to the density of the whole road network, there are relatively few low-lying coastal roads. The problem is, they go through sensitive areas: bordering mangroves (Jennipa), the Bay of Fort de France, north-east coast, and the west coast towards Robert. Their deterioration and leaching during heavy rains and during the cyclone season causes serious pollution and degradation to mangroves, seagrass meadows and coral reefs.

GUYANA

Guyana has 1,400 km of roads: 450 km of national roads, including the main trunk road between Saint Georges de l'Oyapock - Cayenne – Kourou – and Saint Laurent du Maroni, a 6 km expressway around Cayenne, 387 km of regional roads, 495 km country lanes and 500 km of forest tracks (managed by The French National Forestry Department). In addition, there are 3 582 km of dirt tracks that have no administrative staus. Long bridges cross the rivers including the Cayenne (1 300 m), Kourou, Aprouague and Oyapock. All the roadways are subject to deterioration during the rainy season, and road maintenance is consequently problematic. Many structures are subject to marine pressures and the maintenance and monitoring standards are higher than in mainland France.

Road infrastructures have a significant impact on the terrestrial environment, ecosystems are cut off by these linear infrastructures and forests need clearing, or at least the trees need topping to stop them falling over and blocking the road. However, the coastal and marine ecosystems suffer little impact. Guyana has no coral formations, but there are a number of mangroves. However, compared to deposits from large rivers and huge coastal sedimentary movements (like in the Amazon), the impact of deposits caused by deterioration of roads is minimal. The chronic pollution caused by the roads also has a relatively small impact on the marine environment, compared to agricultural pollutants and effluents from urban areas. Furthermore, as there are no lagoons, there is an «open sea» effect and extensive hydrodynamic and sedimentological movements along the coast of Guyana. Finally, except between Cayenne and Kourou, where traffic is dense, relatively few sections of the road are close to the coast,.

MAYOTTE

Mayotte is very different from Reunion Island because economic development is limoted. Mayotte has 225 km of roads, including 88 km of national roads and 137 km of regional roads. There are no expressways. However, there is heavy traffic on some roads, for example, between the ports of Longoni and Mamoudzou and south of Mamoudzou to at least Passamainty and Petite Terre, between the barge dock and the airport and these roads are congested at rush hour. Heavy goods vehicles transport dangerous polluting materials, especially between the port of Longoni and the industrial area of Kaweni. Some sections of the roads are located in low-lying coastal areas and go through mangroves or close to fringing coral reefs, and thus have a strong impact on the environment. Finally, given its geological and geomorphologic characteristics, the island is already subject to massive terrigenous deposits in periods of heavy rainfall, which could increase due to climate change, especially on cut and fill road embankments and river crossings.

FRENCH POLYNESIA

Tahiti is different from the other high mountainous islands and atolls.

Tahiti

Papeete and its surrounding towns are the economic centre of French Polynesia and 70% of the population lives in this area.

Due to the island's morphology (very steep landscape and narrow coastal plains), a ring road goes all the way round the island on the coastal plain (113 km). This road is connected to a small secondary road network giving access to the lower part of a few wide valleys and to residential areas on slopes close to the coastal plain. The ring road runs along the edge of the lagoon or at least close to it.

In the Papeete area, traffic is dense and is congested at rush hour in the direction of the neighbouring towns of Faaa and Punaauia to the west, but also to Pirae and Arue to the north east. There is a 15 km 4-lane expressway between Papeete (West Clearance Road) and and Punaauia (Plains Road).

All the other roads are 2-way traffic (the roadway is 7 m wide).

The effects of climate change will increase the deterioration of these roads during heavy rains in the cyclone season, causing damage to cut and fill embankments, landslides, and mudslides, which, in turn will lead to pollution and degradation of the reef areas which surround the whole island, with hyper¬sedimentation, and pollutants leached from the road. In addition, with the rising sea level, roads located along the lagoon will flood more frequently and suffer serious damage due to more intense cyclonic swells. These weather phenomena will have an indirect effect on the reef environment, with coral suffering from hyper-sedimentation and from pollutants leched from the road; coral reefs may be destroyed by riprap blocks dragged from the road embankment by cyclonic swells.

The Leeward Islands

The morphology of Moorea, Raiatea, Tahaa, Bora Bora, and Huahine is similar to that of Tahiti and most have a ring road on the coastal plain, some also have roads criss-crossing the island. But road traffic is light compared to Tahiti, and there are few chronic pollution problems. Possible future problems linked to climate change could be destruction of road embankments along the lagoons, which would affect the reef flats, plus hyper¬sedimentation due to the collapse of sections of the road that act as local dykes, especially in areas where roads cross the valley.

In distant high islands (Marquesas, Gambier and the Austral Islands) problems will be marginal, given the small road network and light traffic.

The atolls also have small road networks and limited traffic, and so (except for illegal discharge of oil), the problem of pollution of the lagoons will be marginal. On the other hand, as all the roads are low (maximum a few metres above sea level) they are vulnerable to deterioration or destruction which will functionally damage reef formations due to the accumulation of riprap or gravel from the destroyed road embankments.

NEW CALEDONIA

New Caledonia has by far the largest road network of all the French overseas territories, with over 5,000 km of roads in the following categories:

- 575 km of territorial roads (equivalent to national roads in mainland France) managed by the Infrastructure, Topography and Land Transport Directorate (French acronym DITT) in collaboration with the Provinces;
- 779 km of provincial roads (equivalent to regional roads in mainland France) managed by the Provinces, 450 km of which are in the Northern Province, 285 km in the Southern Province and 44 km on the Loyalty islands;
- 3,376 km of municipal and urban roads managed by the municipalities;
- 892 km of rural roads managed by the municipalities.

The Southern Province has expressways: 20 km of 4-lane clearance roads west of Noumea, and 18.5 km of 4-land clearance roads east of Noumea. Only a relatively small proportion of the roads in the network run along the coast; but these may be close to very near sensitive zones, i.e.,mangroves and coral reefs. The impact on these environments can be due to chronic or accidental pollution.

Traffic is very dense (private and heavy goods vehicles) on sections of roads near Noumea and around the northern and southern nickel factories; there is also a lot of traffic between Noumea and La Tontouta Airport, 40 km away (there is an extension project planned for VDO). The nature of the soil and the cut and fill embankment sections means there are higher risks of rockslides, landslides and mudslides in periods of heavy rains and these can occasionally have an impact on fringing reef environments.

Some roads are already old and the increase in traffic, especially heavy goods vehicles, due to major development projects has caused serious damage to some of them as their structure is inadequate and requires frequent maintenance.

As existing roads are already in short supply, the effects of climate change are expected to increase their deterioration.

WALLIS AND FUTUNA

Wallis and Futuna are small and economic activity is limited. The road network reflects this sitiuation:

- Wallis has 63 km of local roads, 50 km of which are asphalted,
- Futuna has 37 km of local roads (the ring road and airport access), of which 25 km are asphalted.

Some roads on Wallis runclose to the coastline and the lagoon and could be affected by ccidental pollution and hyper-sedimentation during periods of low pressure and cyclones.

EPARSES ISLANDS

TROMELIN, JUAN DE NOVA, EUROPE, GLORIEUSE

These islands all have very small road networks and light traffic so environmental pressures from road infrastructure can be considered marginal.

3.3.4. POSSIBLE IMPACTS OF CLIMATE CHANGE ON ROAD INFRASTRUCTURE IN INTERTROPICAL ZONES AND THE CONSEQUENCES FOR REEF ENVIRONMENTS AND THEIR ECOSYSTEMS

Here we refer back to chapter 1 and the IPCC predictions for inter-tropical zones. The major implications for road infrastructure are the following combined effects:

- intensification of cyclones in all tropical regions;
- higher overall and/or occasional rainfall;
- permanent rise in the sea level (higher temperatures) and temporary rises (winds and lagoon bagging).

These phenomena will probably be very violent and have an impact on road networks, particularly those on the coastline or with embankments constructed on marine wetlands (mangroves, mudflats) or fringing coral reefs:

- deterioration of road embankments by destabilisiation of the riprap armour layer, displacement of natural or manufactured riprap blocks over reef flats causing serious damage to coral formationss;
- followed by destabilisation of the core of the embankment and dispersion of fine materials over the reef flat leading to localised asyphxiation of coral formations and seagrass meadows;
- dispersion of the surface layers and asphalt from the road, possibly causing local pollution of sensitive environments;
- destruction of drainage structures and settling ponds, leaching of pollutants that have accumulated in these road structures and occasional pollution of sensitive marine areas (mangroves, mudflats, reef zones);
- roads will be more frequently submersed by floods, accelerating the deterioration of both the embankments and the roads and reducing their durability;
- more frequent leaching of the structures, resulting in pollutants from road traffic being dispersed in sensitive marine areas.

Such deterioration downstream from outfalls may then cause pollution and damage to sensitive marine areas due to massive additions of terrigenous particles, turbid plumes in lagoons and deposits of road-¬related pollutants leaching from the road and settlement basin. The following photographs show some recent examples of damage to structures during the cyclone season.

The increase in rainfall (except during the cyclone season) and in temperature could differ in each tropical region.

Rising temperatures, more intense sunshine and more rainfall can affect the durability of road structure, resulting from deterioration of the asphalt due to the impacts of water and UV rays.

The overall increase in rainfall could also affect the durability of road infrastructure by causing a rise in in the level of the aquifer which can create pore pressure in base layers and foundations, altering their structure, particularly if the sewage and drainage systems are damaged.

Normal maintenance of the coatings of low-lying sections of the roads, (theoretically every 7 years) should at least partially compensate for the rising sea level.

Maintenance procedures for road infrastructure and the management of watershed hydraulics should be reviewed along with the design of future roads (the use of resistant drainable materials, road structure, better quality asphalt, etc.).

Damage after a cyclone in New Caledonia, March 1996. M. Photo: © M. Allenbach

Cyclone Dumille January 2013. Photo: © Réunion 1ere.fr

*Cyclone Dumille January 2013 Reunion.
Road destruction (source Reunion 1ere)*

Dock destroyed by cyclonic waves. Photo © M. Allenbach

3.3.5. TECHNICAL RECOMMENDATIONS FOR ADAPTATION

In light of the above remarks, we recommend **a diagnostic survey of all road infrastructure** which may have an impact on sensitive marine areas (or sensitive coastal areas, but also on the watershed upstream) by the appropriate services. The resutling diagnosis must be uploaded into «Road Data Banks» and «Road structure Data Banks», and if necessary, used to define **technical measures for adaptation** to climate change.

DIAGNOSIS OF EXISTING STRUCTURES

Should include:

- the eomorphologic location of the infrastructures in relation to mangrove and coral ecosystems and a general presentation the context, including the watershed, hydrogeological and hydraulic management and current and potential pressures on the site;
- the geometric characteristics of the road
- (longitudinal, cross-section and altitude profiles);
- characteristics of other structures, in particular, those prone to pollution (rest areas, green spaces, stormwater and pollution management systems etc.);
- a summary of management procedures and incidents, especially during exceptional weather conditions, and measures already taken;
- an analysis of current and potential problems in the design of various structures;
- a summary of projects to repair various structures, or build new road infrastructure.

PROPOSALS FOR TECHNICAL ADAPTATION MEASURES TO CLIMATE CHANGE

These will be the result of a reflection on the possible consequences of climate change and will be taken into account when adapting the management of existing infrastructure and building new infrastructure. They will include:

- **an analysis of external pressures on road infrastructure;** these are mainly in the upstream watershed: risks of increasing periods of heavy rains resulting in stronger river flows and runoff and, consequently, an increase in floods and deposits of terrigenous particles in coastal plains and in the marine environment. Are the current water management structures in the area adequate in the face of the possible effects of climate change? Does the flood risk management plan (FRMP) in the area need reviewing or do the drainage and settling systems upstream from the road infrastructure need changing? Reflection on planning in the area should take future development projects and their possible impacts on the watershed into account, and i include the pressures from climate change. This work must be carried out in collaboration with the different State departments and appropriate local services;

- **an analysis of pressure on road infrastructure. For existing infrastructure.**

Questions which need answering are:

Will current coastal road sea defence structures resist the combined pressure of cyclones and rising sea level? Should they be consolidated? If so, how what additional protective structures should be put in place? Is it necessary to consider relocating some particularly exposed road sections?

Will the structure of exisiting roads (sub-layers and wearing course) resist future pressure (increased temperatures, intensity of cyclones, occasional rain and flooding)?

Are the road drainage systems and their surrounding areas correctly designed to cope with future pressure, or should they be altered, consolidated, enlarged (possibly review the size of ditches, retention basins; flow regulators, hydrocarbon separators)?

Will the specifications for the maintenance of roads and their drainage systems need to be reviewed?

Roads in the watershed zones: will the cut and fill embankments be sufficiently stable if there is an increase in heavy rainfall and should they be consolidated now?

Will the structures crossing rivers (bridges, inverts) resist higher flow rates? *(see Chapter 2)*

Questions concerning future developments

Do studies take the pressures from climate change into account? Should the standards, recommendations, pilot documents, etc., on the characteristics of the materials, road structures, the size of hydraulic structures, and embankment stability, be reviewed?

FURTHER RESEARCH WILL BE REQUIRED ON CERTAIN ISSUES

The answers to a number of the above questions will probably require:

- further applied research, particularly onthe structure of roads (choice of materials, composition and the geometry of the layers that make up the road);
- the creation of a catalogue of standard structures, specifically for roads in French overseas territories and for specific climates (based on the European model for frost-shattered roads);
- additional studies to optimise the models of local climate phenomena, simulating extreme hydraulic situations on and around the infrastructure (hydrology and hydrogeology, calculating watershed flood risks and overtopping); calculating possible swells in the vicinity of structures and optimising potential redesign measures to be taken on defence infrastructure with respect to road infrastructure;
- optimising observation systems linked to climate change phenomena near road infrastructure (possibly setting up additional measuring equipment in weather stations on site, tide gauges);
- research on optimising the design of future roads and road crossing structures in coastal areas.

The above recommendations abave are in «checklist» format to enable the diagnosticians to draft a coherent final document for all the major roads concerned.

3.4. ENERGY-RELATED INFRASTRUCTURE

Most French overseas territories have no fossil fuels and therefore depend on hydrocarbons and to a lesser extent on coal and gas imported by sea. This energy dependence ranges from 87% to 97%, depending on the territory. This is all the more worrying as the number of cars and the consumption of electric power continues to increase (IEOM 2011).

Statistics concerning the share of energy fossils used in producing electricity in overseas territories can be broken down as follows:

- > 90% for Guadeloupe and its dependencies, Martinique, Mayotte, Wallis and Futuna, and Polynesia, except Tahiti,
- 85% in New Caledonia,
- 66% in Reunion Island,
- 62% in Tahiti,
- 44% in Guyana.

The remaining percentages correspond to different forms of renewable energy (hydroelectricity, wind, bagasse, photovoltaic, geothermal, biomass, biogas, marine renewable energy). Most of these renewable energies represent less than 4% per type of energy), except:

- hydroelectricity (dams), which is significant in Tahiti (38%), Reunion Island (20%) and New Caledonia (12%);
- bagasse (10% in Reunion) and photovoltaic power (8% in Mayotte).

«The development of more energy-efficient economic models is an adaptation solution taken without regret for Overseas territories, not only to cope with the direct impacts of climate change on production and consumption, but also to manage rising costs of imported fossil fuels».

(source: Overseas territories facing the challenge of climate change - Report to the Prime Minister and Parliament-ONERC –French documentation IEDOM 2012 and 2011).

3.4.1. SUMMARY OF ENERGY-RELATED INFRASTRUCTURE

All energy-related infrastructure, fossil and renewable fuels, on land and at sea are mentioned here. However, special attention is paid to marine renewable energies, even though they are still underdeveloped in overseas territories, because despite their great and diverse potential, they will have a direct impact on sensitive marine habitats (coral reefs and related ecosystems), the focus of this book.

FOSSIL FUEL RELATED INFRASTRUCTURE

The following infrastructure is found in Frnech overseas territories:

- port infrastructure for offloading different kinds of fuel (heavy fuel oil, gas and coal for electricity production) and motor fuels (petrol, diesel and kerosene). These terminals are located in industrial port areas and require an access channel and deep draft basins. They consist of:
  - docks able to receive tankers, LNG tankers and cargo ships (for coal);
  - mooring dolphins;
  - sea lines;
  - embankments equipped with pipeline systems connecting platforms and storage tanks;
  - coal depot areas equipped with mobile cranes with grabs and equipment for moving coal (cranes, conveyor belts).
- thermal power stations which produce electricity from the combustion of fuel, gas or coal. They use steam and/or diesel turbines; coal power stations also bagasse, a side product in sugar factories.

Thermal power station in Le Port, Reunion Island (source EDF)

RENEWABLE ENERGY RELATED TO INFRASTRUCTURE

Faced with the challenge of climate change, developing renewable energy infrastructure is an opportunity to reduce greenhouse gas emissions, but also to compensate for the high cost of producing electricity.

Such facilities are being developed in the overseas territories.

LAND BASED INFRASTRUCTURE

- **wind turbines:** which transform wind energy into electrical energy. A wind turbine consists of a tower, a gondola that houses the mechanical components, tyres, and electrical and electronic components, and a rotor with several blades of variable size. Electricity is then transferred by cables;
- **photovoltaic panels** are made up of photovoltaic cells which transform solar energy into electricity. Photovoltaic farms often occupy several hectares. Electricity is transferred to the power grid by cables;
- **hydroelectric dams** enable the transformation of the potential and kinetic energies of water behind the damto drive a turbine downstream, with a generator to produce electrical energy;
- **geothermal energy** uses calories in the ground. These calories are used directly and/or converted into electricity;
- **bagasse** is the fibrous residue of sugarcane once the juices have been extracted. It is mainly the cellulose part of the plant and is used as bioenergy in rum and sugar production factories. Efficient installations mean some factories are self-sufficient in energy; bagasse can also be used in coal-fired power stations;
- **biogas** is produced by anaerobic digestion. It is the result of fermentation of plant or animal organic matter in an oxygen free environment (anaerobic). Biogas is primarily methane (CO4) (from 50% to 70%) and carbon dioxide (CO2). As the two gases are combustible, burning them produces heat and/or electricity. Methane is obtained from waste such as sludge from sewage treatment plants, livestock manure, effluents generated by the food industry and discharge from household waste incinerators.

MARINE RENEWABLE ENERGIES

The ocean has extraordinary diverse energy potential based on the wind, currents, waves, thermal gradients, biomass, and osmotic pressure. France has over 11 million km2 of marine waters under its jurisdiction and hence significant potential to use its marine energy resources. By exploiting these resources, France would achieve 3% of its objective by 2020: 23% of renewable energy.

These energies are particularly important for overseas territories firstly because they are favourable sites for implementing some of these technologies and, secondly, they would achieve energy self-sufficiency.

Although these new forms of energy are still rare in France and overseas territories, they are strategic issues for the energy sector in France and in Europe and will therefore have to grow rapidly.

Currently, the infrastructure needed to produce ocean energy is still scarce in the overseas territories. The only systems in place use ocean thermal energy. Two facilities that serve hotels: the «Intercontinental» on Bora Bora since 2006 and the Hotel «Brando» on Tetiaroa atoll exist in French Polynesia.

The information on the different technologies and their potential impacts on the environment below comes from some of the key documents below:

- Marine renewable energy –a forecast up to 2030 (IFREMER 2008) (In French);
- Marine renewable energy - Methodological study on environmental and socio-economic impacts (MEDDE 2012) (In French);
- report on a fact-finding mission on Marine renewable energy submitted to the Ministry of productive rehabilitation, Ministry of Ecology, Energy and Sustainable Development, Ministry in charge of transport, sea and fishing in March 2013 (In French);
- IUCN France (2014) Development of Marine renewable energy and Biodiversity preservation – Summary report for decision-makers. (In French);

Resources that could be harnessed for the production of marine renewable energy are:

- wind: production of electricity by offshore wind turbines;
- mass movement of ocean waters: currents, waves and tides;

Fixed offshore wind towers: the different types of foundations. Source: SAIPEM

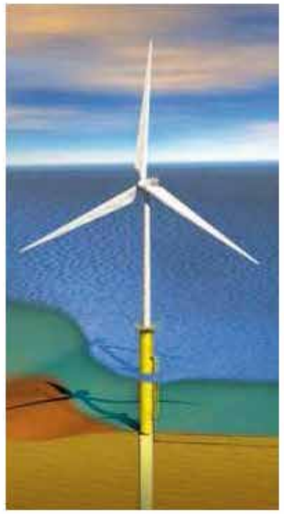


Figure 1: Mono pile, North Sea

Figure 2: Gravity, Cotentin and Brittany

Figure 3: Space frame, Mediterranean

- sea water temperature: thermal gradient between water at the surface and near the seabed, or using the cold seabed layer for the production of cold;
- marine biomass: using marine plants and microalgae;
- osmotic pressure from waters with different degrees of salinity.

WIND ENERGY

Offshore wind turbine towers are either fixed to the sea bed or floating. They are called wind parks or wind farms and are located about 20 km from the coast, in water that is less than 20 m deep.

Fixed offshore wind towers - Alpha Ventus park in Germany. Source: Areva Wind

CURRENT ENERGY AND TIDAL STREAMS

TIDAL POWER PLANTS

These exploit the energy of the tide by using the difference in level between two bodies of water. Tidal energy makes use of the kinectic energy of moving water to drive turbines. Such power plants are still rare because of acceptability issues as well as cost. The Rance Tidal Power Plant is the first large-scale infrastructure of this type in France.

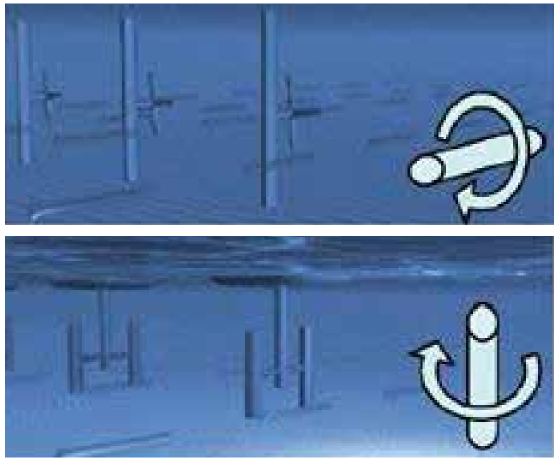
TIDAL TURBINES

Tidal turbines, which use ocean currents or tidal streams as one of the components, can be classified in the following categories:

- **axial drive systems.** These are similar to underwater turbines, the rotor blades convert the linear energy of the marine current into electricity by means of a rotating generator. Turbines may have a horizontal or vertical axis;
- **hydrofoil systems:** this device consists of underwater «paddles» which drive a hydraulic system. The paddles oscillate with the currents thereby compressing hydraulic fluid. This pressure is used to produce electricity;

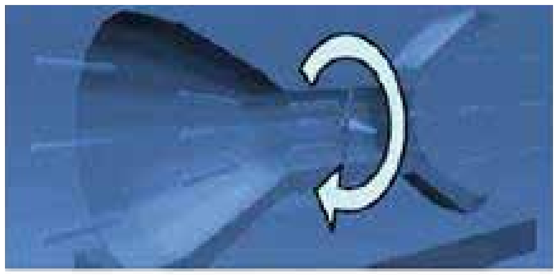
- **«Venturi effect» systems:** this device exploits the acceleration of fluid passing through a constricted section of a pipe.

Around 50 concepts have been developed based on these three principles.



Axial drive systems: horizontal and vertical

Hydrofoil System

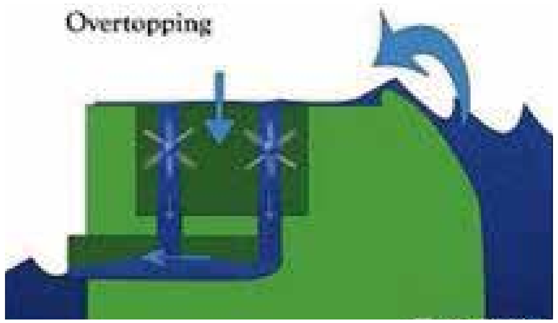


«Venturi effect» system. Methodological study of the environmental and socio-economic impacts of renewable energies. MEDDE 2012 version.

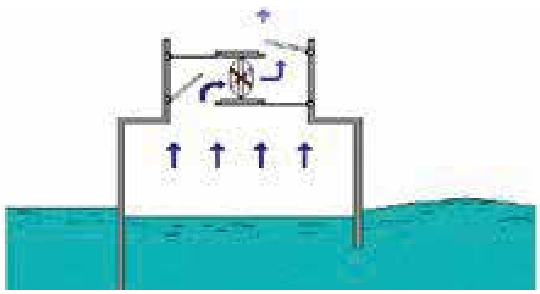
WAVE ENERGY

In this case, energy from the surface motion of waves is used to drive a turbine to produce electricity. There are four main technical principles:

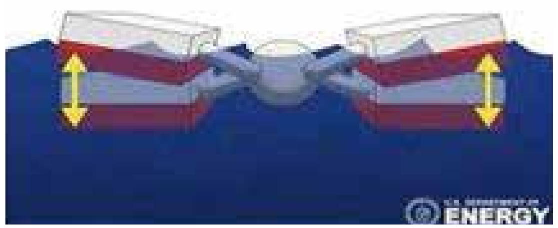
- **overtopping:** Waves breaking on a slope are collected in a high basin and on returning to sea, the water drives a turbine;
- **oscillating water column:** The surface of the sea water acts as a piston to push air in a pipe «blower hole»; in turn, the air drives a turbine which can work in both directions. This type of device can be installed at sea or onshore;
- **floats at the surface:** these devices form an articulated floating structure perpendicular to the waves. They are steel pipes or pontoons connected by hinges containing hydraulic pumps. Wave action pushes hydraulic liquid which then drives a turbine;



© www1.eere.energy.gov/water/hydrokinetic/tech Tutorial.aspx



Oscillating column: http://www.daedalus.gr/OWCsimulation2html



Floats at the surface

- **submerged systems:** they can be oscillated (a component oscillating in both directions via wave action) or operate a hydraulic cylinder piston pump.

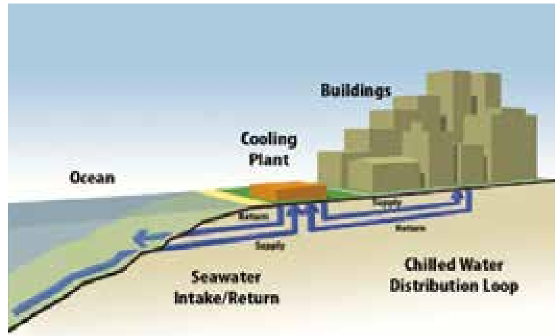
OCEAN THERMAL ENERGY

The ocean is thermally stratified, the upper layers can reach high temperatures particularly in tropical zones (over 24 °C and up to 30 °C), and low temperatures in its depths (about 5 °C at a depth of 1,000 m). One can thus use:

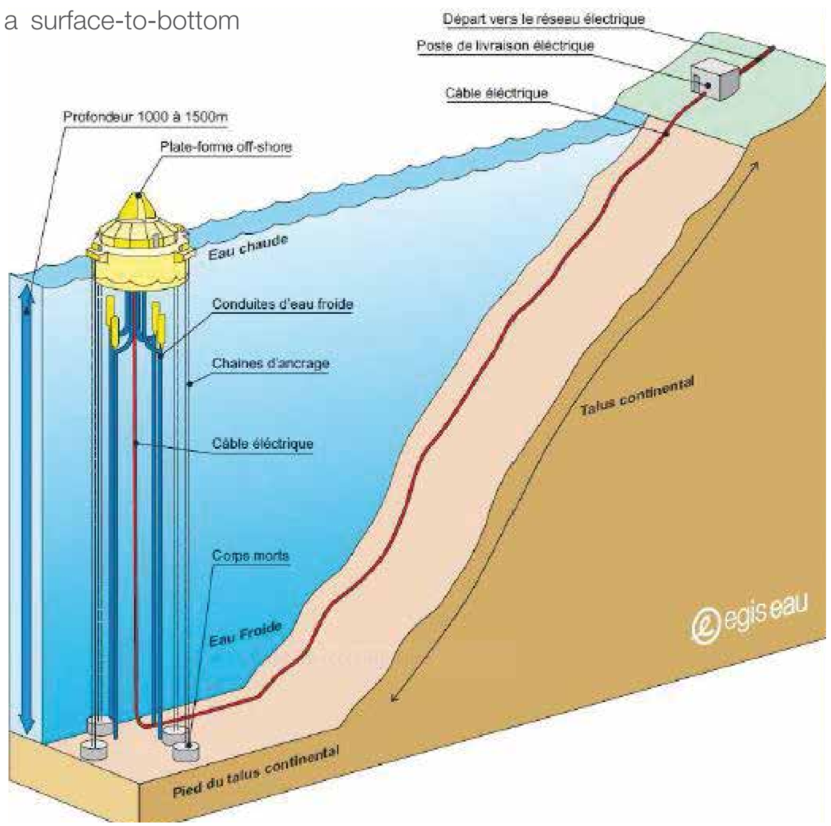
- **either the high temperatures in the upper layers** for heating;
- **or the cold temperatures in deep waters:** for cooling “Sea Water Air Conditioning” (SWAC) for cooling.

There are currently only two functioning sea water air conditioning systems in French Polynesia;

- Thermal Energy Seas (TES) or Ocean Thermal Energy Conversion (OTEC) **located at the point where the temperature differs between surface water and the sea bed layer:** this system uses a surface-to-bottom pump, heat exchanger and turbine generator to produce electricity. This device depends on a fluid which transforms liquid to vapour when it comes into contact with hot water (the sea surface water). The pressure produced by the vapour passes through a turbo generator and drives a turbine. After losing pressure, the gas passes through a capacitor and is transformed back into liquid when it comes into contact with cold water pumped from the seabed. Residual water has a wide range of complementary uses linked or not to the TES, particularly in air packaging and cooling.



Schematic diagram of a SWAC



Schematic diagram of a SWAC © ARER (Reunion Island Regional Energy Agency)

Martinique will be the first French territory to have a pilot Thermal Energy Sea plant which may be commissioned in 2016.

MARINE BIOMASS

Compared to terrestrial oleaginous species microalgae have many beneficial characteristics, such as producing fatty acids which can be used to produce algo-fuel. Their main advantages are that their biomass yield is 10 times that of terrestrial biomass and there is no conflict for the use of freshwater for agriculture. All that remains is to be done is identify the areas that could be made available and try to reduce costs.

SALINITY GRADIENT ENERGY (OSMOTIC PRESSURE)

When two bodies of water with different salinity levels come into contact, the freshwater molecules naturally pass from the less compressed side to the more compressed side to restore the balance. This is called osmotic pressure.

If a concentrated saltwater and freshwater body are separated by a semi-permeable membrane, the freshwater will naturally cross this membrane and the resulting pressure is the equivalent of a 240 m water column, which can be used to drive a hydroelectric turbine. Salinity energy plants should be located next to estuaries, where large freshwater and saltwater bodies are available, thus reducing investment and civil engineering costs.

Research is still required to reduced the costs

3.4.2. IMPACTS OF ENERGY RELATED INFRASTRUCTURE ON THE ENVIRONMENT

IMPACTS OF FOSSIL FUEL INFRASTRUCTURE

- **Oil terminals.** The main risk for the marine environment is from oil spills when fuel is being transferred from oil tankers to storage tanks or a shipping accident when a petroleum tanker is on its way to distribution terminals or to other users. Technical control measures in oil terminals normally help avoid risks of accidental oil spills (SOPEP which quickly neutralises an oil spill in a port or at sea (floating dams, etc.).
- **Gas.** The main risks are due to security problems on site and in the vicinity when there is a fire or an explosion.
- **Bulk unloading sites (coal).** The risk of pollution arises during unloading and transport (chronic and accidental pollution by hydrocarbons, oils and other toxic products, including heavy metals, solvents used for equipment maintenance, and leaching in depot areas and parking lots), as well as dust.
- **For port infrastructure,** please refer to Chapter 3.2. on ports where the impacts of port activities are listed.
- **Thermal power stations:**
  - the most important impacts are emissions of pollutants into the atmosphere (sulphur oxides SOx, nitrogen NOx, carbon dioxide CO_2) and dust;
  - effects of the discharge of cooling water (both the thermal impact and polluting residues) when effluents are untreated;
  - ash, which still contains toxic residues and should be processed and buried in appropriate sites;
  - security related risks: explosions, fires and oil spills into the natural environment (in the case of oil powered plants), especially during extreme phenomena such as earthquakes, tsunamis.

These sites also have a significant impact on land and the landscape.

The French electric power company EDF is currently renovating all its thermal power stations, particularly those in the overseas territories. The objective is to replace their thermal power stations with equipment incorporating the latest technological advances. The industrial performance of the new facilities is better and are more environmentally friendly, see details below:

- they are equipped with new generation diesel engines with optimised yield and reduced CO_2 emissions;
- waste heat recovery boilers will optimise fuel consumption, thus reducing CO_2 emissions;
- the facilities can use environmentally friendly fuels which can be converted into natural gas, when appropriate;
- include protective measures against climate hazards (e.g. dykes against floods and tsunamis).

The thermal energy plant at East Port in Reunion island is modular designed to gradually adapt to the state of development of the island's renewable energies (marine energy, STEP).

IMPACTS OF RENEWABLE ENERGY INFRASTRUCTURE

LAND BASED INFRASTRUCTURE

- **Wind turbines.** The main impact is on the landscape, in the form of noise and avian risks. Their impact on the marine environment is zero or very low;
- **photovoltaic panels.** Their main impact is their surface area and appearance. They require a lot of space and can thus have an impact on other activities, particularly agriculture. They may have an indirect impact on the marine environment in the case of deposits of terrigenous particles during periods of heavy rain, land erosion of sites where photovoltaic panels are installed and of land located downstream. The two other problems are that the panels form a large waterproofed surface which generates significant runoff and their anti-seismic fixation requires soil compaction, which seals the soil. However, some solar farm managers in overseas territories (in Reunion Island in particular) are trying to optimise the land by planting crops between the panels. These measures are taken for economic reasons, but also help stabilise the soil, and should limit or even eliminate the risk of transferring fine sediments to the marine environment during heavy rains thereby avoiding degradation of coral reefs located downstream from solar farms;
- **hydroelectric dams.** These facilities are generally located in a mountainous environment and far from sensitive marine areas. Their major impact is that they form an ecological barrier for the terrestrial environment and the waterway. The marine environment would be significantly affected in the case of a breach, overflow and/or malfunction in the infrastructure, meaning the lagoons would suffer from a sudden intake of water heavily loaded with terrigenous particles resulting in degradation of the coral due to hyper-sedimentation and high turbidity;
- **geothermal energy.** Here the impact on the natural environment is very low or zero. However the noise, vibration, appearance of these infrastructures can disturb residents ;
- **bagasse** power plants: Bagasse/coal power stations release gases into the atmosphere. As bagasse is a plant product, it is considered a renewable resource and direct emissions from the burning process are considered void, similar to other organic compounds, such as wood. And the fact is, the carbon released during the combustion of a plant-based product is offset by the carbon the plant sequestered during its growth, so the net impact is zero;
- **biogas.** The impacts on the natural environment are low to zero (same as bagasse for CO_2 emissions). Potential impacts on local residents could be the smell if existing technical measures to limit it are respected;
- **household solid waste incinerators.** Their major impact is the emission of pollutants into the atmosphere as a result of incineration.. Possible side effects could be macro-waste being deposited in sensitive environments by high winds and heavy rains when the facilities are located near the coastline and precautions have not been taken to manage the waste efficiently.

MARINE RENEWABLE ENERGIES (MRE)

Today, very little infrastructure of this type exists in overseas territories except offshore wind farms and some sea water air conditioning). So its impact on the natural environment is not yet available. However, the following risks are possible.

During heavy cyclonic swells, offshore wind farms using current and wave energy systems and ocean thermal energy structures could be at risk from:

- deteriorating anchorage of the underwater electricity cable network, as well as submersed convertors. This could cause functional damage to coral formations;
- damage to facilities in the landing area and shifting of their components in sensitive environments (riprap or concrete blocks, cables, anchoring systems etc.) causing local functional damage to reef flats along the coast and/or mangroves;
- dispersion of toxic refrigerant products from damaged cooling systems in sea water air conditioning plants;
- collision between vessels and surface structures (wind farms and wave energy facilities, offshore ocean thermal energy plants).
- oil spills; dispersion of toxic products and macro-waste in reef flats and mangroves.

When algo-fuels are produced from marine biomass, the risks are:

- deterioration of marine biomass production areas due to rising sea level and strong cyclonic swells, with impacts on neighbouring reef environments (hyper-sedimentation and asphyxiation, functional destruction by dyke components beibg dragged across reef flats or in mangroves);
- disruption of the production of microalgae, due to changes in the quality of the water in the production areas due to heavy tropical rains and rising water temperature. If these basins overflow into nearby relatively confined coral areas, there will be a significant risk of eutrophication, which may lead to coralline algal blooms.

Salinity gradient energy systems (osmotic pressure and reverse electrodialysis) are still at the experimental stage.

3.4.3. ENERGY RELATED INFRASTRUCTURE IN THE OVERSEAS TERRITORIES

GUADELOUPE

(93% dependent on fossil fuel energy)

FOSSIL FUELS

Fossil fuels provide almost 91% of the electricity supply, despite a huge natural potential for renewable energy: geothermal resources could be used to produce electricity, and the large quantities of bagasse left over from sugar cane pocessing could also be exploited. Diesel power stations are located in:

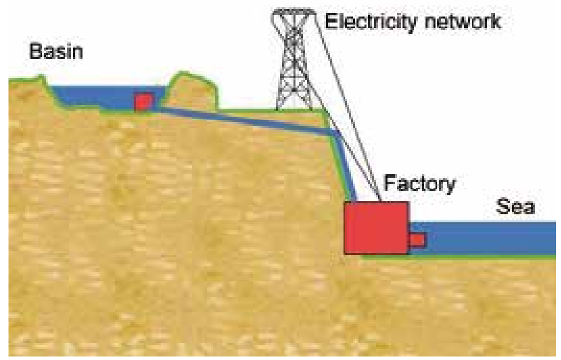
- Jarry North diesel (167.2 MW) and Jarry Sud turbine combustion (102 MW), these will be replaced by a a new diesel power plant, diesel (220 MW)at Pointe Jarry ,which started operating in stages in 2014:;
- Folle Anse (Marie Galante): EDF diesel back¬up plant (7.1 MW);
- La Desirade: EDF diesel back-up plant (0.9 MW);
- Les Saintes: EDF diesel back-up plant (2 MW);
- Saint-Martin: two facilities, one is EDF (39 MW) and the other EDF EN (14.3 MW).

In addition, there is the industrial port infrastructure at Pointe Jarry, where the SARA refinery unloads and stores its hydrocarbons, where gas is filled and stored (RUBIS) and coal is also stored.

MIXED AND RENEWABLE ENERGIES

- Moule thermal power station: bagasse and coal (64 MW);
- Bouillante geothermal power station (15 MW) on the west coast of Basse-Terre;
- three EDF hydroelectric power stations: Le Carbet (4.6 MW), Canal St Louis, and Bananier (3 MW);
- twelve wind farms (total power: 27 MW). All the wind turbines are foldable during cyclones. They are located in Anse Bertrand, Petit Canal, Saint Francois, Capes Marie Galante, La Desirade, Terre de Bas.

Some projects are under study: a sea water air conditioning plant (SWAC) for the hospital in Basse Terre and a marine STEP station (energy transfer by pumping)for use in peak consumption hours) developed by EDF SEI. to compensate for intermittent outputs of renewable energy such as solar and wind power, to limit the impact of fluctuating production on electrical grids and enable more than 30% of their instantaneous power in the mix. A 50 MW STEP storing 0.6 GWh could be adapted to the system in at Petit Canal, Guadeloupe.



Marine STEP Project (pumping energy transfer station by, © EDF SEI)

LA MARTINIQUE

SARA refinery in a mangrove area in Fort de France Bay. © lemarin.fr

(97% dependent on fossil fuel energy)

The remaining 3% are supplied by incineration of household waste, and wind and solar power. There is an oil terminal in the port of Fort de France and a refinery which supplies Guadeloupe and Guyana. Hydrocarbons are loaded and unloaded using pumps, and transported by pipelines to the SARA Refinery located in Lamentin. This refinery is located near mangroves in the bay of Fort de France.

FOSSIL FUELS

Thermal power comes from two diesel power stations and six combustion turbines:

- Pointe des Carrieres diesel power station operated by EDF (81 MW);
- Bellefontaine diesel power station operated by EDF (199 MW) is being renovated, the new one (220 MW) is part of the renovation and environmental improvement programme of all EDF thermal power stations;
- two combustion turbines (4.8 MW each), located in Lamentin that belong to the SARA refinery supply the company's oil refinery, excess electricity is sent to the EDF network;
- two combustion turbines at Pointe des Carrieres power stations 2 and 3 (20 MW each). A new one (27 MW) brings btotal production up to 66 MW;
- Bellefontaine A power station is also equipped with a combustion turbine producing 23 MW;
- Galion power station, operated by Galion Cogeneration Company, which is part of the Albioma group, has a combustion turbine (40 MW).

LAND BASED RENEWABLE ENERGY

Since Martinique is not particularly suited to this type of energy production, it remaines largely undeveloped. Efforts are underway to include more renewable energies in the mix in the future. The Regional Council has set itself the target of producing 50% of its energy using renewable resources by 2020. These include:

- incineration of solid household waste, which is the only source of constant renewable energy on the island (4 MW) and produces 2% of electricity. It is operated by Martiniquaise for CACEM;
- wind energy is limited to a small area in the upper part of Basse-Pointe because the coastal area is densely populated making it

difficult to operate there. Local wind energy is only produced by the Aerowatt wind farm at Vauclin (1.1 MW);

- solar energy: despite representing such a small share of the energy mix on the islands, solar energy is the one being developed in Martinique as it has the greatest potential (60 MW end of March 2013).

Many renewable energy projects are planned in Martinique:

- a biomass power plant in Galion in 2015, with a capacity of 34 MW;
- increasing the production capacity of the household solid waste incinerator;
- creating a biogas recovery unit in Trompeuse;
- building new wind farms equipped with electrical energy storage devices;
- a geothermal project;
- building a biomass furnace at CACEM;
- building mini-hydraulic production units on the Lorrain, Case Navire and Lezarde rivers;
- setting up an ocean thermal energy prototype production unit;
- reflecting on designing fuel cells and ethanol fuel;
- finally, Martinique has launched a project to import gas; Bellefontaine's new fuel power plant can be adapted to this gas.

MARINE RENEWABLE ENERGY

The directorate of French naval shipbuilding (French acronym DCNS) is studying two ocean thermal energy (OTE) plant projects. The principle of ocean thermal energy is a constant energy baseline, which could replace the coal and oil-fired power plants in Martinique.

An «onshore» thermal marine energy plant is under consideration in Martinique - (source DCNS Akuo). It is a 4 MW onshore pilot ocean thermal energy power plant connected to the electricity grid, as a forerunner of a series of ocean thermal energy power stations (10 MW offshore); construction is planned at Bellefontaine on EDF owned land in 2016.

Schoelcher is studying a sea water air conditioning plant project and several cold and heat network projects are under study in the suburbs of Fort de France (source EDF SEI).

GUYANA

(over 81% dependent on fossil fuel energy)

Fossil fuels supply 44% of electrical energy, hydroelectric dams 54%, wood 0.6%, and photovoltaics the rest.
Thermal power stations and hydroelectric dams provide around 50% of total electricity in Guyana.

FOSSIL FUELS

The French Electricity Company, EDF, manages three diesel power stations:

- Degrad des Cannes power station (112 MW) in Remire-Montjoly, which supplies the Cayenne network;
- Kourou thermal power station (22 MW turbine combustion);
- small diesel generators in St. Laurent-du¬Maroni and inland villages (Regina, Kaw, Grand¬Santi, Apatou, Papaïchton, Maripasoula, Saint-Georges, Camopi and Ouanary).

Ports which receive hydrocarbons are:

- Degrad Cannes, equipped with an oil terminal to receie oil in bulk. The hydrocarbons are then transported by pipeline to the SARA depot;
- the fishing port of Larivot in Cayenne also has a SARA depot to supply fishing vessels;
- Pariacabo port near Kourou has an oil terminal and a fuel hydrant system which supplies the SARA depot in Kourou;
- inland regions and villages are powered by generators and small solar installations.

RENEWABLE ENERGIES

These are represented by several different systems:

- Petit-Saut dam (115 MW), which supplies two thirds of electricity production.
- Saut Maripa hydropower plant (1.3 MW), which supplies St-Georges-de-l'Oyapock;
- An EDF biomass plant called Voltalia in Kourou (2 MW);
- small solar power stations in Saul and Kaw;

A river turbine (about 50 kilowatts) is being tested by EDF on the Oyapok river. This electricity production in a rural area would replace the current 100% reliance on diesel generators.

MARINE RENEWABLE ENERGIES

Biomass, hydraulic, wind, solar, diesel projects are under study to diversify and complement Guyana's electric power mix.

REUNION ISLAND

Reunion Island uses several categories of electricity production: firstly fossil fuel thermal power stations (87% energy dependent), followed by renewable energy, and hydroelectricity, bagasse, biogas, wind, and solar energy.

The island has set itself the target of electrical autonomy by 2030, focused on the use of bagasse and marine energies.

The French Electricity company EDF is currently experimenting with the largest European cell (NaS cell) which will provide high-tech energy storage. A NaS sodium-sulphur cell, with a 1 MW power capacity was built in Saint Andre in November 2009.

FOSSIL FUELS

Fossil fuels represent 66% of electric power production. Four thermal power stations currently operate on Reunion Island:

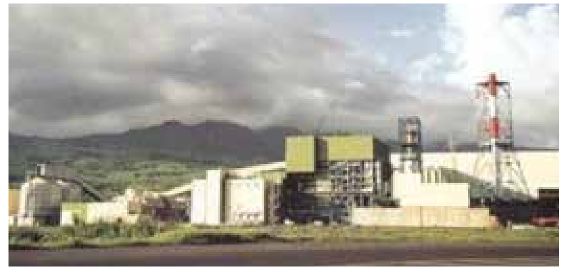
- «Le Port» (East), diesel engines (220 MW power capacity) commissioned in 2013;
- «La Baie», with two combustion turbines with 80 MW power capacity;
- «Bois Rouge», bagasse and coal system, with 100 MW power capacity;
- «Gol», bagasse and coal system, with 111 MW power capacity.

The bagasse-coal power stations, designed by Sechilienne SIDEC Company, are innovative in that they combine two functions in one facility: firstly, they are the sugar factory's boiler, where the bagasse is burned with low pollution, and secondly, it is an electric power grid, with the same reliability and availability characteristics and which, in addition, complies with antipollution measures.

An industrial port site (Le Port) has the necessary port infrastructure to unload fuel and coal for its diesel and coal power stations. The La Baie and Le Port power stations are operated by EDF and Bois Rouge and Gol by Sechilienne Sidec, renamed Albioma in June 2013.

RENEWABLE ENERGIES

- **Bagasse:** Reunion Island produces 550,000 tons of bagasse annually, which are almost entirely used by the two thermal power stations at Gol and Bois Rouge. In 2010, bagasse was used to produce 10% of electricity (see § above bagasse/coal power stations),

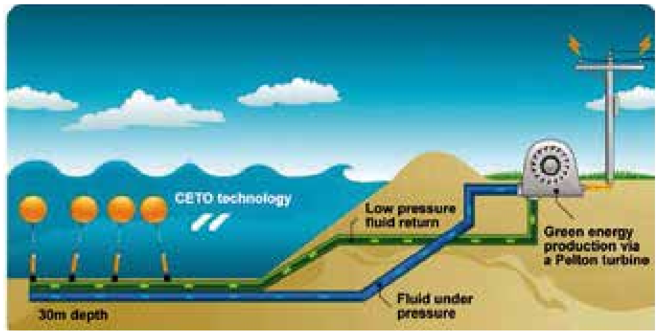


Gol coal-bagasse thermal power station. Source: ©Arer Mayotte report 2011

- **Five hydroelectric power stations** produce electricity: «Sainte-Rose» hydroelectric power station on Riviere de l'Est (91 MW), «Takamaka 1» and «Takamaka 2» (43.4 MW), «Bras de la Plaine» (4.6 MW), «Langevin» (3.6 MW) and Bras des Lianes (2.2 MW). They are maintained and operated by EDF, except Bras des Lianes which is run by the Regional Council;
- **biogas** is represented by the biogas power station at Riviere Saint ¬Etienne, which has been in service since 2008. It transforms waste into biogas which is then used to produce electricity; it is operated by Veolia and has a capacity of 2 MW;
- **wind and solar:** over the last five years, wind

and solar power undergone considerable development on the island. There are a number of small: privately owned and company run wind or solar power units, including «La Perriere» (8.5 MW) wind farm run by Aerowatt and «Sainte Rose «(9 MW) solar farm run by EDF,

- **several marine renewable energy projects are currently under development:**
  - Ocean Thermal Energy Projects: a sea water air conditioning (SWAC) project is underway in Saint-Denis and Sainte Marie (a GDF-Suez/CDC project); which should reduce power consumption by 80%, compared to a standard cold production system (the SWAC sea outfall: Saint-Denis / Jamaica, air conditioning network in the Saint-Denis/ Sainte-Marie urban coastal area and certain buildings: hospitals, the airport, the university, Sainte Marie business park).
  - other studies are underway to use deep water biotechnology: another SWAC project is planned for southern Reunion Island hospital group in Saint Pierre. This is an ADEME-EDF project to introduce marine powered air conditioning in its buildings. The objective is to reduce electricity consumption for air conditioning by over 50%.
  - Three wave power converter projects are under study, two in Saint-Pierre, one in Saint Philippe.
    - A wave power project based on Pelamis-Seawatt technology: power production by a wave power converter farm (a 2nd generation PELAMIS technology developed by PWP, a Scottish company), with efficient energy storage (oleo strut) for islands with an overall 30 MW power capacity (Saint-Pierre/Pointe du Diable with anchorage at depths of 75 to 150 m);
    - a wave power project based on CETO-EDF EN technology: electricity production by submerged wave energy converters. The project consists of buoys (activators) laid on the seabed which are set in motion by wave energy. The wave energy is then transferred to a pump which puts fluid under pressure. The fluid is transferred via an underground steel pipe network to a turbine connected to a generator which transforms the energy into electricity (offshore at Pierrefonds, Saint-Pierre). The challenge for Reunion Island is an industrial consolidation at home and abroad (in the Northern Hemisphere), studies are underway to peepare the way for this prototype stqge. Once in the industrial stage the project should have 15 to 20 MW power capacity.
    - a project for an onshore wave energy converter at Saint-Philippe, taking advantage of the planned construction of a dyke and adding a structure capable of using wave energy, which is very powerful at this location (~ 20 kW/m), of converting it into electricity (Saint-Philippe slipway, pilot phase in Saint-Philippe (≈ 600 kilowatts)). There are other possible ways of using this technology at other sites in Reunion Island, including the future coastal road (a 6 km dyke), or in marine wharf projects (Saint Andre and Saint-Louis) currently under discussion by the Reunion Regional Energy Agency.



A wave energy converter project based on CETO-EDF-EN technology in Saint Pierre, Reunion.

Onshore wave power converter project in Saint Philippe (source EAR)

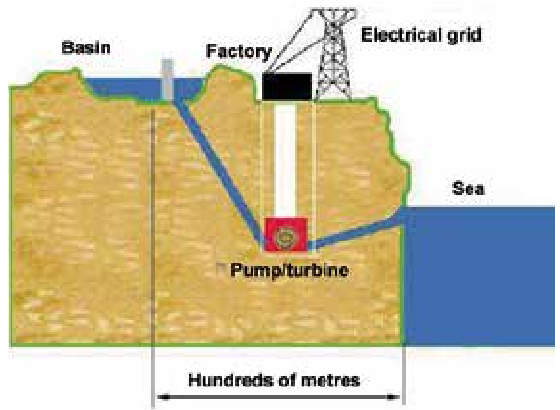
The following should also be mentioned:

- the onshore ocean thermal energy (OTE) prototype project (PAT OTE) and the Directorate of French Naval Shipbuilding (DCNS). The aim is to use the difference in temperature between the sea's surface waters and deep waters to produce electricity (IUT in Saint Pierre, Reunion Island). The PAT OTE project set up a model OTE test bench to validate numerical models developed by the French naval industrial group DCNS for an electricity power system. The aim is also to demonstrate the feasibility of implementing OTE technology and to define an optimal energy system before

incorporating it into a marine power station; new thermodynamic cycles, with other heat transfer fluids, and other materials could also be tested (new heat exchangers, etc.).

- the offshore OTE power station run by Reunion Island and the DCNS: The aim is to build a pilot offshore ocean thermal energy power station (7 MW) connected to the power grid, as a

forerunner for a series of ocean thermal energy power stations (25 MW), 9 km offshore from Le Port, at a depth of 1,500 m.



MARINE STEP Storage facility © EDF-SEI

IDENTIFIED CHALLENGES FOR REUNION ISLAND'S ELECTRICITY PRODUCTION

- Reunion's Regional STARTER project: up to 100 MW power capacity by 2030, SRCAE (in progress); unknown potential by 2020; estimated potential 25-100 MW power capacity in 2030;
- the OTE principle would ensure that a basic energy supply is constantly available, and would replace coal power plants (an OTE demonstration/feasibility study was conducted in 2009, work is underway to overcome risks, and the first steps will be taken to connect to an offshore power station before 2020);
- Sainte-Rose's pilot osmotic energy electricity production project, using the difference in salinity between seawater and freshwater from the Riviere de l'Est's hydroelectric plant to produce electricity. The technical and economic feasibility of this type of project has not yet been demonstrated as there is only one industrial scale project in operation, in Tofte (Norway) since October 2009;
- the MARINE STEP Storage facility (energy pumping station) to develop intermittent marine renewable energies (MRE), operated by EDF (source EDF - SEI); this project aims to store energy to overcome peak consumption periods, particularly in the island's southern region. Levelling intermittent renewable energy production, such as solar and wind power,

could limit the impact of their fluctuating production on the electrical grids. A 50MW STEP storing 0.75 GWh seems to be possible in «Matouta» near Saint Joseph.

MAYOTTE

(Over 92% dependent on fossil fuel energy)

Ninety-one percent of all electricity is produced by **two diesel thermal power stations:** One, Badamier power station (38.1 MW) is located on Petite Terre and has been in service since 1987, and the other, Longoni power station (40 MW) is on Grande Terre and has been in service since 2009. The use of renewable energies is limited to photovoltaic cells.

A 2011 study entitled «Renewable Energy Scenarios to meet Mayotte's energy needs by 2030» was led by the Reunion Island Regional Energy Agency. Technological, financial, regulatory feasibility scenarios were built based on combining SWAC-UBC2E (Bio Cogeneration Unit for Electricity and Drinking water) to meet the demand for electricity, drinking water and air conditioning. In this scenario, the cold generated by sea water air conditioning and the heat from the thermal plant are used to distil the sea water.

FRENCH POLYNESIA

(89% dependent on fossil fuel energy)

Papeete's port has oil and butane gas unloading terminals and oil and gas depot areas. The main problem for the population and for local activities is its proximity to Papeete's urban centre, in the case of a fire or an explosion. The neighbouring coral environment is at risk. This site also services the archipelagos.

In Tahiti, fossil fuels represent 62% of electricity production in thermal power stations operated by Tahiti Electricity company (French acronym EDT). The main one is in the Punaru'u valley (Punaauia IZ). The remaining 38% is produced

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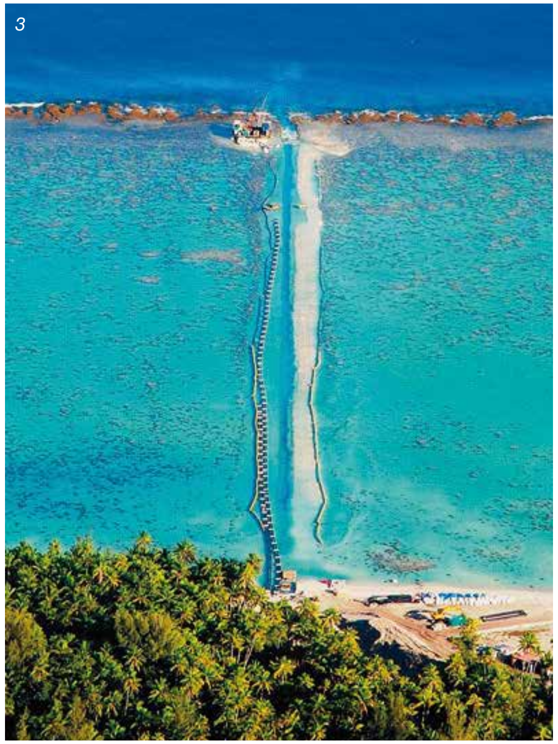


1: aerial view of Tetiaroa atoll and its pipe installation,
2: view of the underwater pipeline and its fixations,
3: aerial view of pipeline installation on the reef flat.

by 20 small dams.

Solar and wind energy is increasing in the atolls.

MARINE RENEWABLE ENERGIES

Two SWAC (sea water air conditioning sytems) have already been operating at Bora-Bora Hotel Intercontinental hotel since 2006 and «The Brando» Hotel on Tetiaroa Atoll since 2014, others are under study including one for the hospital in Papeete.
French Polynesia has set itself a target of producing half its electricity from renewable sources by 2020 and 100% by 2030.

NEW CALEDONIA

(96%dependent on fossil fuel energy)

This dependency is the result of high demand from the transport and industrial (metallurgical and mining) sectors and lack of primary energy resources. Fossil energy supplies 85% of electricity, renewables 15%, of which 12% hydropower and wind power and 3% solarpower;

FOSSIL FUELS

Electricity production is mainly ensured by thermal power stations fuelled by:

- heavy fuel oil: Doniambo and Nepoui;
- diesel: Pine Islands, Loyalty Islands, Pouebo, Poum,
- coal: Prony Energies, KNS-North plant.

In 2009, the Prony energy power station (Mont-Dore region) introduced coal into New Caledonia's energy mix. The SLN processing company in Noumea needed to replace its aging oil powered station and opted for a new coal power station. The northern SLN plant, which is responsible for economic growth in the developing Voh-Kon e-Pouembout (VKP) area, also chose coal as its energy source., Three coal power plants have been built in less than 10 years, ranking New Caledonia at the top of the list of the worst greenhouse gas emittors among French overseas territories. What is more, the power stations are located close to several New Caledonian lagoon reef areas which are classified as World Heritage sites for their exceptional biodiversity.

LAND BASED RENEWABLE ENERGY

- Hydropower is the most developed with dams on the Yate, Thu and Neaoua rivers;
- wind power, most wind farms are located in the southern part of Grande Terre;
- photovoltaic power is currently being developed (farms are planned).

MARINE RENEWABLE ENERGIES

Academic reflection and prelilinary -studies are underway, but they are lagging behind compared to other French overseas territories, which are similar in size and have similar economies.

WALLIS AND FUTUNA

(More than 97% dependent on fossil fuel energy)

FOSSIL FUELS

Ninety-nine percent of electricity production relies on fossil fuel. Wallis has an oil and gas unloading terminal at Halalo and a depot area, and Futuna has a petroleum unloading terminal and a depot area.

Both Wallis and Futuna Islands have a diesel power station.

LAND BASED RENEWABLE ENERGY

They are only four small photovoltaic production units and Futuna has a small hydroelectric unit. The possibility of establishing others is being explored.

MARINE RENEWABLE ENERGIES

A reflection process is still underway on using wave energy in access channels to the lagoons in Wallis.

3.4.4. POSSIBLE IMPACTS OF CLIMATE CHANGE ON ENERGY RELATED INFRASTRUCTURE AND THE CONSEQUENCES FOR REEF ENVIRONMENTS AND THEIR ECOSYSTEMS IN INTERTROPICAL ZONES

FOSSIL FUELS

Risks for port infrastructure receiving hydrocarbons, for oil refineries and thermal diesel power plants are the increasing intensity of cyclones and submersion due to the rising sea level (see Chapter 3.2. on «Port infrastructure»). Risks from deteriorating infrastructures can be serious for sensitive environments (mangroves and coral reefs), especially if certain parts of the facilities (pipelines, storage tanks) are damaged. These are major risks for a refinery. In addition, leaching in parking lots and depot and maintenance areas will pollute reef flats (heavy metals, hydrocarbons, macro-waste). Bagasse-coal power plants appear to less risky for sensitive marine areas.

RENEWABLE ENERGIES

- **Land based wind farms:** in the event of deterioration of these structures due to climate change, the impacts on the marine environment will be low to non-existant;
- **solar farms:** the risks will be low for the marine environment, except during heavy rainfall in the cyclone season, as they can cause land erosion between the photovoltaic panels and lead to high terrigenous deposits in the sea, especially in coral reefs;
- **hydroelectric dams:** the risks will be due to increased intensity of heavy tropical rainfall which may cause overflowing or destroy the structures. In addition, for the population living downstream, the risks are linked to the durability of the structure and water supply; and the consequences of sudden large masses of turbid water, loaded with fine and coarse sediment and all types of rubble for the coral reefs;
- **biogas:** no major pressures;
- **geothermal energy**: no major pressures.

MARINE RENEWABLE ENERGIES

The major impact of climate change will be the need to reinforce the structures in view of more intense cyclones (winds and swells). The deterioration or even destruction of infrastructures is also a risk.

- **Anchorage in shallow waters** (wind turbines, tidal turbines, wave energy convertors and submersed cables linked to machinery; sea water air conditioning pipe fixations, can cause functional damage to coral formations and seagrass meadows near or next to the fixations, cables and pipes, especially to the outer slopes which are generally teeming with life.
- **Floating structures** (wave energy convertors and offshore ocean thermal energy platforms): some of the components of these structures could drift and risk colliding with boats, as well as causing local functional damage to reef flats. Boat collisions can cause injury to humans and material losses, but can also pollute reefs or mangroves if they involve an accidental spill of oil or of the contaminants contained in various products stored onboard the destroyed or drifting vessels.
- **Landfall or coastal structures** (wave energy oscillating column system, aboveground ocean thermal energy structures, substations, pumping stations), these infrastructures could deteriorate due to strong swells and high winds; the predicted rise in sea level increases the risk of submersion. This can then result in the functional degradation of sensitive marine and coastal ecosystems located nearby (coral reefs, mangroves, coastal vegetation) and accidental pollution when pollutants leak from the facilities (refrigerants in sea water air conditioning systems, for example).

Both marine renewable energy recovery systems (artificial lagoon wave energy convertors and algo-fuel production) will be affected by the following risks:

- **artificial lagoon wave energy convertors:** the risk that the dykes protecting lagoons are destroyed and deterioration of buildings (particularly on the offshore side in the case of systems set up on motus [islets]). Destruction of the dykes would functionally damage coral formations and neighbouring coastal vegetation by dispersing rocks or terrigenous particles and deteriorated buildings could cause accidental pollution (low risk) linked to motorised machinery or to polluting products used for the maintenance of the facilities';
- **Structures linked to algo-fuel production,** the risks are:
  - whether the marine biomass production basins will survive a rise in sea level and strong cyclonic swells;
  - microalgae production conditions could be disrupted by changes in the basins' water quality due to heavy tropical rains and an increase in water temperature;
  - deterioration of rhe basins could then cause functional damage to reef formations and coastal vegetation in the vicinity, including mangroves. There could be biological implications for neighbouring ecosystems if production basins spill out water loaded with microalgae through breaches in the dykes, especially in confined environments (eutrophication, plankton bloom, algal proliferation that alters the ecosystem).

3.4.5. TECHNICAL RECOMMENDATIONS FOR ADAPTATION

Given the above mentioned remarks, we recommend actions that are appropriate to each type of major infrastructure are carried by the relevant services and private operators involved in the projects.

FOSSIL FUEL RELATED INFRASTRUCTURE

FOSSIL FUEL RELATED INFRASTRUCTURE

- **For port infrastructure receiving hydrocarbons and for refineries,** risks are linked to the increasing intensity of cyclones and submersion due to the rise in sea level (see chapter 3.2 Port infrastructure). As there are major risks to residents and the natural environment near a refinery in a coastal area (SARA refinery in Martinique, for example), this type of infrastructure falls within the SEVESO¬type installation framework and the future risks linked to climate change must be taken into account: reinforcing protection structures against extreme sea conditions and flooding, consolidating structures that could be subject to high winds, reinforcing structures and enlarging stormwater collection and treatment systems, including pollutants from such incidents in these facilities; implementing rapid response measures when major incidents occur and in the case of risks of environmental pollution (POLMAR SEA plan);
- **Thermal power stations,** the risks of more intense cyclones are the same and power stations along the coast could flood during cyclones and due to the rising sea level. These risks have already been taken into account by EDF in the renovation of its thermal power stations (for example in the Le Port power station on Reunion Island, protective dykes have been raised to cope with the risk of tsunamis). All the other structures located on the coast or nearby that face the same risks will have to be checked. The risk of deteriorarion of bagasse-coal power stations needs to be checked to ensure the durability of the a structures. The risks to marine sensitive areas are likely to be very low.

LAND BASED RENEWABLE ENERGY INFRASTRUCTURE

- **Land based wind turbines:** no particular problems.
- **Solar farms:** the main risk is terrigenous deposits in lagoons during heavy rains, the risk of erosion of the land on which solar farms are located and areas downstream, depending on their geomorphology (landscape, soil types, slopes) and their proximity to coral environments. The land between the panels should be stabilised by planting crops and the

panels' rainwater collection system optimised.

- **Hydroelectric dams:** the quality of existing structures and their ability to support higher flow rates due to climate change will need to be checked if such measures are not already planned. Special attention should be paid to the capacity of the flood spillways.
- **Biogas**: no particular problems.
- **Geothermal energy**: no particular problems.

INFRASTRUCTURE RELATED TO MARINE RENEWABLE ENERGY

EXISTING STRUCTURES

Currently, there are only two facilities in operation, they are both sea water air conditioning systems located in French Polynesia. We recommend:

The diagnosis of existing structures should include:

- the infrastructure's geomorphologic location with respect to coral ecosystems and a general description of the context that highlights the site's current and potential pressures;
- the characteristics of the structures, of their pipelines and the geometry of their anchorage;
- the characteristics of technical buildings and those of polluting structures (refrigerants, equipment, and maintenance products);
- the characteristics of any hotel infrastructure linked to sea water air conditioning systems, as they could have an impact in extreme weather conditions;
- a summary of the management procedures of the structures and possible incidents, especially during exceptional weather conditions and the measures that need to be taken;
- an analysis of current and possible future problems in the design of structures;
- a summary of projects to repair, extend or adapt various structures;

Technical recommendations based on the diagnosis of existing structures:

- reinforcing pipe fixations and anti-cyclone defences on buildings with sea water air conditioning and possibly hotel facilities as these may affect SWAC facilities during cyclonic swells, coastal flooding, high winds and very heavy rains;
- a possible review of the maintenance procedures for these structures: regular and more frequent inspections of pipe fixations, their condition, possible weak points in the landfall zone, building maintenance and technical cooling infrastructure.

Offshore OTE power station in Martinique. Photo: © DCNS

FUTURE STRUCTURES

Analysis of external pressures on marine renewable energy infrastructure

The pressures on infrastructures built in coastal areas are linked to the corresponding watershed: risk of more frequent heavy rains increasing river flows and runoff and consequently, increased risk of flooding and deposits of terrigenous particles in the coastal plains.

The issues to be addressed are:

- Are the area's current water management structures adequately designed for the foreseeable effects of climate change? Should the area's flood risk management plans be reviewed and drainage structures and settling ponds upstream from a marine renewable energy power station adapted?
- Reflection on planning in the area must take future development projects and their possible impacts on watershed zones into account by including pressure due to climate change. This should be carried out in collaboration with the appropriate State departments and local services.

ANALYSIS OF PRESSURES ON MARINE RENEWABLE ENERGY RELATED INFRASTRUCTURE

The issues to be addressed are:

- Will the sea defence protections of marine renewable energy buildings in landfall zones be able cope with the effect of future cyclones and rising sea level? Should their design be adapted? If so, what additional protective structures should be put in place? Will it be necessary to consider moving or abandoning certain projects in some very exposed sites?
- Are the fixation systems of underwater pipes and cables designed to withstand future more intense cyclones?
- Does the design of dykes protecting tidal system basins (artificial lagoons) and biomass production basins take into account the predicted rise in sea level and the increased intensity of cyclonic swells?
- Do the specifications for maintenance procedures need to be reviewed?

Further research required on certain issues

The answer to a number of questions mentioned above will probably require:

- additional studies to optimise models of local climate phenomena, to simulate extreme hydraulic situations on and around the infrastructure (hydrology and hydrogeology, to calculate the risk of flooding in the watershed and overtopping); to calculate possible swells in the vicinity of structures and optimise measures to be taken regarding defence infrastructure;
- to optimise observational systems linked to climate change phenomena near infrastructure (possibly additional measuring equipment in weather stations on site, tide gauges);

The above recommendations are in «checklist» format to enable the diagnosticians to draft a coherent final document for all facilities related to energy, as a function of the type of infrastructure.

Hotel complex in Bora Bora, French Polynesia. Photo Maria Michelle

CHAPTER 4

4 / INFRASTRUCTURE LINKED TO COASTAL ACTIVITIES

This infrastructure is located on land or on embankments along the shoreline, on slopes near the coast, and sometimes even in the marine environment. They include tourist facilities, artisanal or industrial areas, urban areas (businesses and collective and individual housing), fisheries, aquaculture, oyster pearl farming and agricultural activities.

4.1. TOURIST INFRASTRUCTURE

Climate change will affect tourist infrastructure and how it functions in inter-tropical coastal areas, and will require changes in leisure activities. Significant transformations can thus be expected.

4.1.1. SUMMARY OF TOURIST INFRASTRUCTURE AND ITS IMPACT ON THE NATURAL ENVIRONMENT

OVERVIEW

The facilities discussed here are mainly linked to the hotel industry whose infrastructure can have a significant impact on the natural environment. Others, such as marinas have been dealt with in Chapter 3.2. Port Infrastructure.

Hotel facilities on the coast in French overseas territories in inter-tropical zones can be classified in four major categories according to their size, the type of infrastructure, and their potential impact on the natural environment.

Type 1:
Lightweight structures composed of bungalows for accommodation and hotel activities (management, maintenance, restaurants, bars) and facilities for beach activities and water sports.
Some luxury campsites may be in this category. Such structures are sometimes on the public maritime domain within the 50 metre geometric limit; if this is the case, theoretically, structures can be dismantled. Above and beyond their biological barrier effect, these developments do not have an impact on the actual site.

Type 2:
Concrete buildings in a landscaped park located on the shoreline comprising a few structures which alter the geomorphology of the site.
These facilities required small-scale coastal plain backfilling, dune reprofiling or terraced slopes, but there are no artificial structures on the beach or in the marine environment.

Type 3:
Concrete buildings in a landscaped park which required substantial earthworks and/or the construction of specific structures on land. Such structures are located on slopes (requiring backfill or embankments) and/or on filled coastal plains, such as:

- Land protection structures (to stabilise slopes) placed at the base of embankments, bordering the shoreline (e.g. walls, rockfill embankments);
- Beach reprofiling, sand filling, creating artificial beaches (raised or alveolar beaches), building small groynes.

Type 4:
Large hotel resorts consisting of concrete buildings in a landscaped park requiring substantial earthmoving and the construction of specific structures on land or in the marine environment:
Sea bed reprofiling (in reefs or mangroves) to create swimming areas, navigation channels, the building of pontoons, bungalows on stilts, dams and breakwaters, large groynes, the creation of artificial islands and lagoons, small marinas or anchorage areas for the hotel's water sport activities, these may be included in both type 3 and 4 infrastructures above.

The facilities, structures and equipment which can have a negative impact on sensitive natural environments include:

- buildings (especially workshops for the maintenance of the equipment required to manage green spaces, and waste management areas);
- sewage treatment plants and possibly their outlets;
- hydraulic structures for the management of stormwater;
- reinforced cut and fill or replanted embankments;
- protective structures: walls, rockfill embankments, breakwaters;
- pontoons, bungalows on stilts;
- motorboats.

IMPACTS OF HOTEL INFRASTRUCTURE ON THE NATURAL ENVIRONMENT

These facilities had a significant impact on the natural environment during their construction, but this is also true when they are up and running as their activities may pollute the soil, the vegetation, the groundwater table and any sensitive environments in their vicinity (particularly the mangroves and coral reefs found in French overseas territories in inter-tropical areas).

The main problems are:

- chronic pollution due to oil, fuel, heavy metals deposited on land and at sea by motor vehicles. The level of pollution is usually very limited, but accumulates over time;
- pollution of the landscaped parks due to the use of herbicides, insecticides, fungicides and anti-mosquito treatments. Both the maintenance machines and the products used pollute the natural environment through infiltration into the soil and leaching during periods of heavy rainfall, when the pollutants are transported to sensitive natural areas, including lagoons;
- accidental pollution and deterioration, both of which usually occur after technical or human accidents or during exceptional weather conditions:
  - accidents during handling of polluting products (tank spills or damaged pollutant storage equipment);
  - malfunctions in a water treatment plant or stormwater management system, for example as a result of extreme weather conditions.

These different types of pollution risks are generally taken into account in the design of new hotel infrastructure and the hotel staff are trained in the management of these risks.

4.1.2. OVERSEAS TERRITORIES HOTEL INFRASTRUCTURE

The impacts of tourist infrastructure on sensitive natural environments vary with the territory.

REUNION ISLAND

Most coastal tourist infrastructure is on the west coast, where the marine reserve is located. The infrastructure consists of hotels (buildings and landscaped parks), bars along the upper beaches and public recreational areas (picnic areas) on the dunes, under the filaos trees.

MAYOTTE

Tourism is undeveloped and mainly consists of diving and watching whales and dolphins in the lagoons. There are a few hotel complexes with small-scale infrastructure: some hotels are located in landscaped grounds on the shoreline and on nearby slopes, but none have coastal protection structures or artificial beaches. The smaller hotels consist of bungalows near the beach or on nearby slopes.

EPARSES ISLANDS

There is no hotel infrastructure on these islands; tourism is limited to irregular visits by the «Marion Dufresne», a ship which supplies the islands and is also used for scientific missions.

WEST INDIES

GUADELOUPE AND ITS DEPENDENCIES

There are a number of large hotel resorts (e.g. in Gosier, Sainte Anne, Saint-Francois), especially along the west coast of Grande Terre because of its fringing reefs. The resorts have a number of different structures: buildings in landscaped parks, land protection structures, beaches and swimming areas, as well as small moorings for boats belonging to the hotel used for water activities and which are protected by walls, rockfill embankments, small dykes, breakwaters, or groynes. Some beaches were reprofiled and some small artificial beaches have been created. These structures are located both on the coastline (coastal plains, dunes, slopes) and on small cliffs and coastal protection structures in the marine environment.

There are also large hotel resorts along the coast in Saint Martin. Some were built on sand dunes, others on artificial islands, particularly near Marigot, on embankments. A few have artificial channels leading to a small marina (e.g. in Anse Marcel).

The structures are located in different types of sensitive environments: sand dunes, coral reefs, mangroves, wetlands and lagoons (especially the large lagoon which provides a very sheltered anchorage area).

There are many hotel complexes in Saint Barthelemy, but most are on slopes and only a few affect the marine environment directly.

MARTINIQUE

Martinique has a number of big hotel resorts, most of which are located in Les Trois-Ilets, across the bay from Fort-de-France, in the south-west around the Bays of Sainte Anne and Sainte Luce, and in the south-east and east in Vauclin, and Robert. Like in Guadeloupe, these hotel complexes are built in landscaped grounds, sometimes with artificial and alveolar beaches and coastal protection structures: walls, rockfill embankments, small dykes, breakwaters, groynes and small marinas that belong to the resort.

SOUTH PACIFIC

FRENCH POLYNESIA

Of all the French overseas territories, tourism is most developed in French Polynesia thanks to its vastness, many islands, and beautiful landscapes that are the result of its geomorphological characteristics. The hotel complexes in the many resorts are very varied, thanks to the protection provided by the reefs. The hotel complexes are on:

- high, mountainous islands bordered by large reef formations consisting of fringing reefs, deep lagoon channels giving access to great barrier reefs, with small islands dotted around the lagoon and shallow reefs;
- atolls protected by a reef crown with many islets (motus).

Tourism developed mainly between 1985 and 2010.

Large hotel complexes were created with the same infrastructure as the territories listed above, but in addition, in French Polynesia, they include bungalows on stilts, artificial islands, reef reprofiling to create swimming areas, and navigation channels. On Bora Bora in particular, on the on motus, there are artificial lagoons filled by the ocean, and real lagoons.

NEW CALEDONIA

The geomorphology of New Caledonia is very different from that of French Polynesia. New Caledonia is made up of a very long island, Grande Terre, and a few medium-sized islands (Ile des Pins and the Loyalty Islands: Mare, Lifou and Ouvea). New Caledonia was awarded World Heritage status for its diverse reef geomorphology and exceptional conservation. All the different types of reefs can be found there: fringing reef flats, coral pinnacles, and reef barriers.

Its lagoon is the largest in the world and is very deep; its hydrodynamics are like an inland sea. After Australia's Great Barrier Reef, the New Caledonian barrier reefs are the second largest in the world, they are discontinuous and partly submerged. The island's coastline is consequently less well protected than in French Polynesia because these passages are open to sea. In the other hand, New Caledonia has large mangroves, whereas French Polynesia has practically none.

Tourism is less developed in New Caledonia than in French Polynesia. The main resorts are located around Noumea, on Ile des Pin, a few on the Loyalty Islands and in the Northern Province.

The hotels around Noumea mostly consist of buildings in a landscaped park on the shoreline. The beaches are usually reprofiled, artificial and protected by groynes. The hotel grounds are occasionally made up of embankments, protected by walls or rockfill embankments. Only one hotel on an islet has a few bungalows on stilts.

WALLIS AND FUTUNA

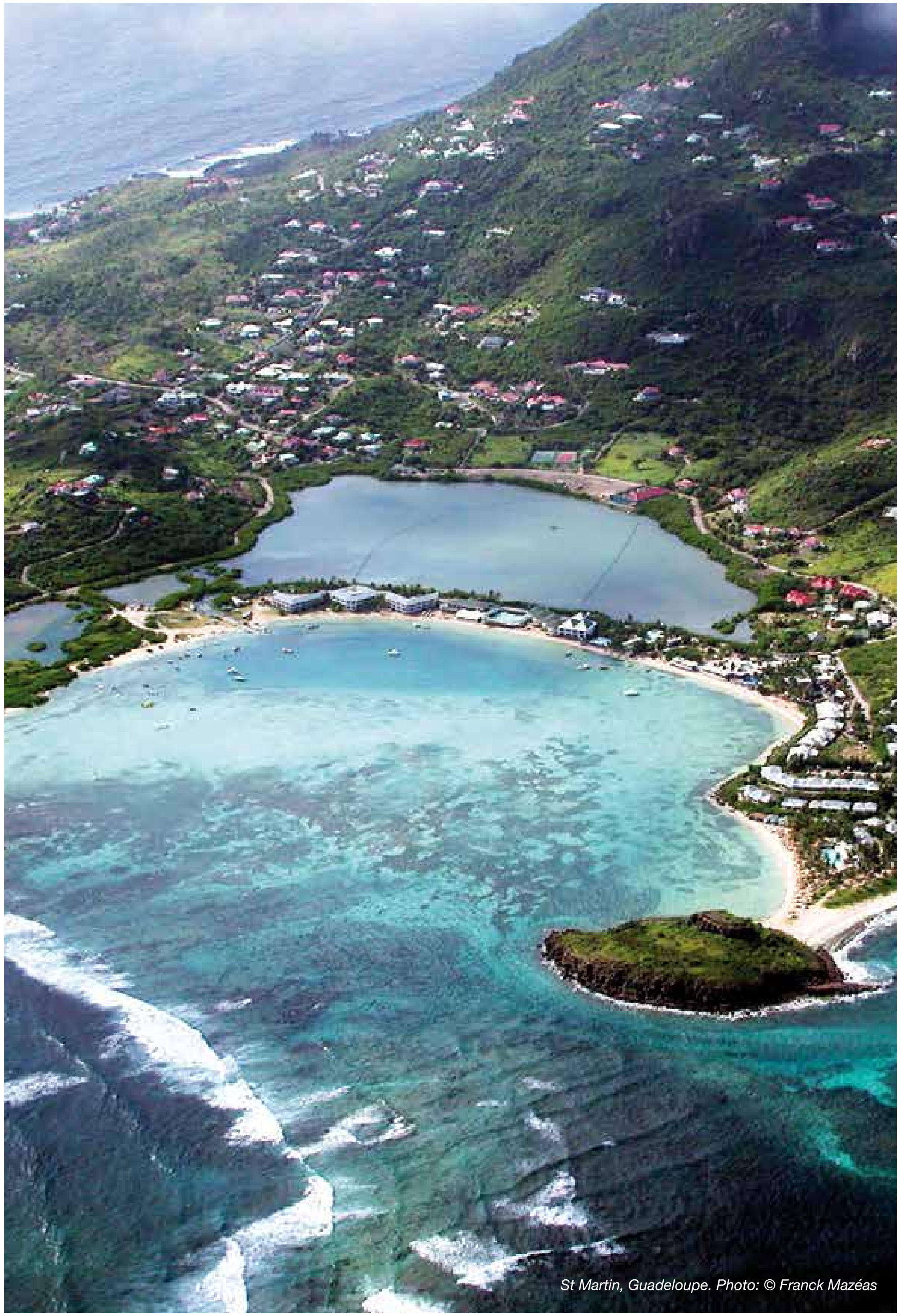
Although these islands have a beautiful reef complex with islets on barrier reefs, tourism is still undeveloped due to their remoteness and size. There are only a few small hotels located in the coastal plain and they have no infrastructure that affects the coastline or the marine environment. Some small walls protect the land, especially in the periphery of Wallis.

Table 6 lists the main types of hotel complexes in each overseas territory, their geomorphologic location and the level of pressure on the environment caused by the infrastructure:

THE DIFFERENT TYPES OF HOTEL AMENITIES IN COASTAL AREAS IN THE OVERSEAS TERRITORIES

Name of territory	Types of hotel complexes (for definition the types, see below)	Geomorphological location	Environmental pressure: * = Low, ** = average, *** = high
Reunion island	1 and 2	Dune, coastal plain, near fringing reefs	* to **
Mayotte	1 and 2	Coastal plain, slopes, near fringing reefs and mangroves	*
Eparses Islands, Europa, Tromelin, Juan de Nova, Glorieuse	0	Coral islets	0
Guadeloupe	1 to 3 many type 4	Coastal plain, slopes, near fringing reefs and mangroves	**
Saint Martin	1 to 4	Dune and coastal plain bordering lagoon, fringing reefs and nearby wetlands	* to ***
Saint Barthélémy	1 to 2	Coastal plain, slopes, near fringing reefs and wetlands	* to **
Marie-Galante	1 to 2	Coastal plain, near fringing reefs	*
Dominique	1	Coastal plain, near fringing reefs	*
Desirade	1	Coastal plain, near fringing reefs	*
Saintes	1	Coastal plain, near fringing reefs	* to **
Martinique	1 to 3 many type 4	Dune, coastal plain, near mangroves, fringing reefs and large seagrass meadows	* to **
French Polynesia	all types, many type 4	Coastal plain, slopes, near or on fringing reefs and barrier reef flats, ring of reefs around an atoll and islet (motus)	* to *** numerous ***
New Caledonia, Ile des Pins and Loyalty Islands	1 to 3 many type 4	Dune, coastal plain, near fringing reefs and mangroves	* to **
Wallis and Futuna	1 to 2	Coastal fringe	*

Table 6: Different types of hotel complexes in the coastal areas of French overseas territories and collectivities, geomorphological location and environmental pressures. (Type of hotel complex: Type 1: Lightweight structures consisting of bungalows, Type 2: Concrete buildings in a landscaped park; Type 3: Concrete buildings in landscaped grounds with a lot of structures; Type 4: Large hotel complexes. Please refer to Chapter 3.1.1 for the full definition of the different types of complexes).



St Martin, Guadeloupe. Photo: © Franck Mazéas

4.1.3. POSSIBLE IMPACTS OF CLIMATE CHANGE ON HOTEL INFRASTRUCTURE AND THEIR CONSEQUENCES FOR THE REEF ENVIRONMENT AND RELATED ECOSYSTEMS

The key impacts on hotel complexes will be caused by the combined effects of:

- the intensification of cyclones with higher maximum winds and heavier occasional rainfall
- the rising sea level.

These phenomena are likely to have a very violent impact on hotel infrastructure built on atolls, but also on hotels located in coastal areas of high mountainous islands because they will also be affected by the upstream watershed with steep slopes.

INFRASTRUCTURE ON THE COASTAL FRINGES OF HIGH MOUNTAINOUS ISLANDS

The effects of climate change on complexes located near coral reefs may include erosion of the slopes under heavy rains, destabilisation of cut and fill embankments, mudslides and/or landslides transporting terrigenous particles and turbid waters to the lagoons. This will cause both asphyxiation and degradation of coral reef flats. French overseas territories are vulnerable to these phenomena because their excavated, terraced slopes are usually made up of ferralitic alterite soils.

The following types of pollution can be added to the above degradation problems:

- leaching in sealed off areas (hydrocarbons, maintenance products);
- potential malfunctions in stormwater and wastewater drainage systems and pollutant processes (undersized structures causing pollutants to overflow into sensitive areas);
- more intense cyclones and a rising sea level will cause coastal flooding which will destabilise beaches and coastal protection structures, and land or backfill degradation upstream.

These phenomena and the issues described above will transport terrigenous particles into lagoons, remove blocks and rubble from damaged backfill embankments and coastal protection structures, pollutants and possibly various macro-wastes. These additions to the seabed will damage reef habitats and seagrass meadows, by both asphyxiation and large rocks being dragged across shallow reef flats). Macro-waste and fine sediments will accumulate on the seabed in confined areas (at the bottom of artificial swimming areas built on the reef, in navigation channels, in artificial lagoons, and in the angle along the base of coastal protection structures (groynes, dykes, small marinas).

Examples of beach erosion and coastal destabilisation after heavy storms on the left in Hienghene. Photo: Michel Porcher
On the right: Loss of sand around filaos trees in Reunion Island. Photo: ©BRGM

HOTEL COMPLEXES ON ATOLLS

The increasing intensity of cyclones, and hence of cyclonic swells, will result in serious flooding in hotel complexes, deteriorating or even destroying buildings and hotel facilities, especially those located on the coastline. The combination of low depressions, swells and rising sea level will cause flooding and thusland degradation and leaching. This will result in hyper-sedimentation phenomena and inputs of pollutants and macro-waste in coral environments on the lagoon side. Fine sediments, pollutants and macro-waste will accumulate in confined areas in the lagoon in resorts located in coastal plains on high mountainous islands due to the geometry of certain coastal and marine hotel complexes.

SPECIFIC REMARKS CONCERNING BUNGALOWS ON STILTS

The stilts and floors of these distinctive buildings, which are mainly found in French Polynesia, could deteriorate significantly (cracked stilts, bridges and pontoons destroyed, roofs damaged) in the cyclone season if high winds and swells intensify. This has already happened in recent cyclones.

SOME EXAMPLES OF DETERIORATION OF STRUCTURES IN THE CYCLONE SEASON

However, on reef environments, the impacts will be limited to occasional deposits of macro-waste.

At these sites in the medium and long term, the bungalows on stilts will have to be altered, rebuilt or even removed due to the rising sea level, environmental pressures, and the likely increase in the intensity of extreme weather conditions.

Given the relatively short service life of such structures (a few dozen of years) and the amount of maintenance work they require , adaptation techniques should be adopted progressively over time, according to field observations of how climate change affects pressures.

PHENOMENA IN THE CORAL ENVIRONMENT AND THEIR IMPLICATIONS FOR TOURIST ACTIVITIES AND HOTEL BEACH PROTECTION STRUCTURES

Coral formations are likely to suffer seriously from climate change, mainly from the predicted rise in sea temperature which can cause coral bleaching and lead to their mortality. In addition, the predicted increase in acidification of the oceans would reduce coral growth rate (a chemical phenomenon that reduces the growth of scleractinian polyps calcium carbonate skeletons).

Photo An example of white coral sand being removed from a lagoon to re-fill a resort's beaches. Photo: © Jean Pellissier

These effects will eventually damage the coral reefs, which will have two major consequences for tourist activities and resorts:

- less attractive diving conditions, especially with snorkel and mask on the reef flats located right in front of the hotel;
- the beaches will be less protected and therefore, more likely to erode. Coral reefs play an important role in reducing wave energy onshore (approximately 80% of the offshore swell is reduced by shallow coral reefs). This issue will not only increasingly inconvenience beach activities but the beaches themselves will also need re-filling more often. This will have financial, technical, and environmental consequences, as white coral sand deposits are becoming rare and their exploitation raises serious problems for sensitive environments, particularly in coastal plains or lagoon environments.

These pressures require a review of resort development strategies and the choice of possible activities in the medium to long term at least, depending on the development of the sites.

4.1.4. TECHNICAL RECOMMENDATIONS FOR ADAPTATION TO CLIMATE CHANGE

Given the above mentioned remarks, we recommend a diagnosis of hotel infrastructure in coastal areas by the appropriate overseas territory services (Department of Environment and Tourism) and hotel operators (managers and architects). This diagnosis should be on the effects of climate change on accommodation, activities, sensitive coastal and marine environments. It could culminate in proposals for technical measures for adaptation to climate change for existing infrastructures, if required, and guidelines for adapting future projects over the short, medium and long term.

DIAGNOSTIC SURVEY OF EXISTING INFRASTRUCTURE

This should include:

- the geomorphological location of the infrastructure with respect to coral and mangrove ecosystems and a brief description of the context, including the watershed zone, hydrogeological and hydraulic management, and identification of current and possible future pressures on the infrastructure;
- a description of the main features of the hotel complex (types of buildings, dimensions, distance to the coast);
- a description of specific amenities and structures prone to deterioration that would cause pollution or damage to sensitive natural environments: pollutant and waste storage areas, sewage treatment plants and sea outlets, stormwater management systems, maintenance areas for motor boats, stabilising structures for cut and fill embankments, coastal protection structures, artificial beaches, pontoons, bungalows on stilts;
- a summary of management procedures and previous incidents, especially those that occurred during exceptional weather conditions, and the measures taken;
- an analysis of current and potential problems in the design of various structures, including managing terrigenous deposits during heavy rainfall events, coastal erosion (beaches) and deterioration of structures during heavy storms and cyclones, damage caused by flooding;
- a summary of plans to repair existing structures, or to build new infrastructure.

REFLECTION ON THE POSSIBLE CONSEQUENCES OF CLIMATE CHANGE, TAKING THEM INTO ACCOUNT WHEN DRAWING UP ADAPTATION MEASURES, IN MANAGING EXISTING STRUCTURES OR BUILDING NEW INFRASTRUCTURE

ANALYSIS OF EXTERNAL PRESSURES ON HOTEL INFRASTRUCTURE

These pressures originate in the upstream watershed, they take the form of more frequent periods of heavy rains, resulting in increased river flow and runoff, and consequently, an increase in flooding and terrigenous deposits in coastal plains and in the marine environment.

The following points require evaluation:

- can the current design of water management structures in the area cope with foreseeable climate changes? Should the area's flood risk management plans (FRMP) be reviewed, and do the drainage systems and settling basins located upstream from the hotel need to be adapted?
- any general reflection on planning in the area needs to account for future development

projects and their possible impacts on the watershed zone, by including pressure due to climate change.

This analysis should be carried out in collaboration with the appropriate State and local services.

ANALYSIS OF ISSUES CONCERNING THE HOTEL INFRASTRUCTURE

The questions concerning existing infrastructure that need to be addressed are:

- Will embankment stabilisation structures (cut and fill) still be sufficiently stable if rainfall becomes heavier or should they be reinforced now?
- Will the bridges and fords crossing rivers or streams in the resorts withstand higher water flows?
- Will current structures built for protection against marine erosion and submersion (embankments, walls, rockfills, groynes, breakwaters, small dykes) cope with more intense cyclones and rising sea level? Should they be consolidated? If yes, what type of additional protective structures should be built? Will it be necessary to consider moving back some particularly exposed sites, or phasing out that particular tourist activity?
- Are the stormwater drainage and wastewater treatment systems designed to cope with future pressures, or should they be adapted, reinforced, enlarged (check the size of gutters, settling basins, flow rate controls, hydrocarbon separators)?
- Do the specifications in the maintenance procedures for stormwater drainage and wastewater treatment systems need to be reviewed?
- Are buildings or certain marine structures adapted to the likely increases in the intensity of cyclones (higher wind speeds, stronger swells and submersion phenomena), particularly their foundations, dimensions (resistance of their roofs, bungalow stilts, floors and pontoon characteristics, floating dock anchorage and sea outlets)?
- Can the premises used to store toxic products, hydrocarbons, or maintenance machinery withstand cyclones or severe flooding with no risk of pollution of groundwater, mangroves and lagoons, or should the measures to secure them be reviewed?

ISSUES TO BE ADDRESSED IN FUTURE DEVELOPMENTS

When choosing sites, all possible pressures caused by climate change should be taken into account. The pressures should also be taken into account in all studies: should a structure's height be optimised? should the standards of construction materials be reviewed? How will the choice and size of different structures e affected?

FURTHER RESEARCH ON CERTAIN ISSUES

Projects for hotels should take into account the results of additional studies proposed for large infrastructures (see Chapters 1 and 2).

- Additional studies should be carried out to optimise models of local climate phenomena, to simulate extreme hydraulic situations around and on the infrastructure (hydrology and hydrogeology, the risk of watershed flooding and overtopping should be calculated, along with possible swells in the vicinity of the structures and optimisation measures to be taken to improve defence infrastructure;
- Observation systems linked to climate change phenomena near the infrastructure may need to be optimised (additional measuring equipment may be required for on-site weather stations, tide gauges);

The recommendations above are in «checklist» format to enable the diagnosticians to draft a coherent final document with respect to all relevant hotel developments.

4.2. INDUSTRIAL AND ARTISANAL ACTIVITIES

The impacts of industrial and artisanal activities were discussed in previous chapters, for details on wastewater management, please refer to Chapter 2.2.

4.3. HOUSING AND URBANISATION

4.3.1. DESCRIPTION AND IMPACT ON THE NATURAL ENVIRONMENT

HOUSING INCLUDES

INDIVIDUAL HOUSING

- On the one hand, traditional, even ancestral or conventional (houses, carbets) housing, are still built with traditional, local materials. These homes are scattered on coastal plains, on islands and islets (motus), in valleys, slopes and forests. Their impact on the environment is insignificant. When the houses are grouped in small villages, their impact increases slightly, mainly due to the clearing or deforestation required to create the village and to the waste produced by this small population. The inhabitants usually obtain water from wells or rainwater storage tanks.
- On the other hand, «modern» housing, are built with conventional building materials (concrete, blocks, prefabricated components, wood or metal structures, sheet roofing, tiles). Such houses are scattered in natural areas, or concentrated in villages and large towns. They generally have a well or a drinking water supply system and either semi-collective or collective sanitation systems. Waste management varies depending on the site.

TEMPORARY HOUSING

These are temporary homes or shantytowns on the outskirts of major cities. The buildings are built with recycled materials (corrugated iron sheets, concrete blocks, etc.). These houses have no direct access to drinking water, sanitation is non-existent, and there is no structured waste management system.

COLLECTIVE HOUSING

This consists of apartment buildings with one or several floors. These apartment buildings are located in major cities, but are also often found in housing developments outside cities. This is especially the case on island slopes with a dense urban population, most of whom live along the coast. These homes are connected to a drinking water supply and semi-collective or collective sanitation system. Waste is managed at waste management centres with a collection system.

IMPACTS OF HOUSING ON THE NATURAL ENVIRONMENT DURING THE CONSTRUCTION STAGE

The main impacts are deforestation and soil destabilisation caused by excavation, especially on steep slopes in Tahiti for example, where many individual houses required extensive cut and fill work.

This kind of work rarely complies with standards. Thus, the most common problems encountered are:

- cutting the slopes at too steep an angle, inadequate stormwater drainage systems, or no drainage system at all, no fast growing vegetation planted after construction ended, no management of terrigenous particles resulting from cutting the banks during the construction phase and heavy rains. Sometimes surplus terrigenous materials are pushed by bulldozers into talwegs, but when the first heavy rains occur, these materials run into valley bottoms and lagoons;
- backfilling (often illegal) to extend the area of a property on the coast and in the inner part of fringing reef flats. Backfilling during construction destroys the sea bed due to terrigenous deposits and indirectly affects neighbouring areas. The backfill is usually then stabilised by a vertical concrete wall or

rockfill which has a very negative effect on the coastline and on the stability of the beach (see Chapter 2: Coastal protection structures and Chapter 4.1. Tourist infrastructure).

IMPACTS OF HOUSING ON THE NATURAL ENVIRONMENT AFTER CONSTRUCTION

There are many impacts, including:

- soil sealing by buildings, car parks and access roads which result in increased runoff during the rainy season and increase the risk of erosion, slope destabilisation and flooding in valley bottoms and coastal areas;
- household pollution, litter and bulky waste is left on the ground in some valleys, and depending on their nature, may pollute both soil and water, but also block the passage of water thus causing flooding during heavy rains and deterioration of stormwater management systems. Some of this macro-waste ends up on reef flats or in mangroves, thereby contributing to the pollution of these sensitive environments;
- pollution of rivers, of the water table and ultimately of the marine environment due to illegal discharge of wastewater (see Chapter 2: Stormwater and Wastewater).

4.3.2. HOUSING AND URBANISATION IN OVERSEAS TERRITORIES

Very similar urbanisation trends are underway in all French overseas territories but pressures can vary considerably depending on the territory concerned; for example, the situation in Reunion Island is not the same as in New Caledonia and the size of the settlements affects the phenomena. The populations of these remote regions usually live along the coast for different reasons, but mainly to have access to the outside world via the sea.

In very steep mountainous islands, geomorphic constraints led populations to group in coastal plains, which may be very narrow (a few dozen to a few hundred meters wide in Polynesian islands). In Guyana, most of the population lives along the coast because of the Amazon forest.

Dense urbanisation in coastal plains has resulted in its gradual spread into valleys and slopes when these are accessible, which is the case in Reunion Island and Tahiti.

The following statistics underline the situation:

- Guyana: Cayenne (the capital) contains 69% of all buildings and hosts 54% of the population;
- Guadeloupe: Pointe a Pitre and Basse-Terre are the main developed areas;
- Martinique: urbanisation is mainly around Fort de France;
- Reunion Island: 20% of the island's housing developments are located in Saint-Denis, 16% in Saint Paul and Le Port and 19% in Saint-Pierre and Le Tampon. Furthermore, 15% of housing on the island is shantytowns;
- Mayotte: 43% of housing is shantytowns;
- French Polynesia: 69% of the population is located in Tahiti and in the urban area around Papeete. There are no other large cities; the few villages have between 1,000 and 3,000 inhabitants;
- New Caledonia: 66% of the population lives in Grand Noumea;
- Wallis and Futuna: about 10 000 inhabitants on Wallis (Uvea) and 5,000 on Futuna, most live in individual contemporary houses.

Populations in coastal areas will continue to grow, following the global trend.

4.3.3. POSSIBLE IMPACTS OF CLIMATE CHANGE ON HOUSING AND CONSEQUENCES FOR REEF ENVIRONMENTS AND RELATED ECOSYSTEMS

The major impacts are increased risks of flooding, landslides, coastal erosion, and fewer available resources. These impacts may cause degradation or even the destruction of buildings, with an effect on coastal and insular economy and higher costs of protection or even relocation in the most affected areas. Communities are already facing this kind of situation today including some tribes on the Loyalty Islands (Ouvea) and in the Northern Province of New Caledonia. Taking all the overseas territories together, 25 000 buildings, covering 516 hectares are located below sea level. The consequences for the marine environment and particularly coral reefs are the likely increase in the different forms of pollution linked to housing.

4.3.4. TECHNICAL RECOMMENDATIONS FOR ADAPTATION

It will be necessary to:

- reduce current susceptibility (i.e. through strategic retreat and risk prevention) and future vulnerability (i.e. through urban zoning). Human exposure to hazards must be reduced and activities strategically relocated, housing and infrastructure threatened by destruction, in other words, there is a need for a policy for strategic retreat inland;
- design a comprehensive global management plan for exposed assets that cannot be relocated;
- draw up a comprehensive policy to reinforce good practices;
- continue to control urban planning with risk prevention plans, but also take into account and mention natural risks in planning documents, and prevent construction in areas which are exposed to hazards;
- promote demographic and economic rebalance on mid-slope terrain through large-scale housing developments;
- preserve the protective ecosystems;
- assess and map vulnerability and increase monitoring;
- develop a risk management system.

For technical recommendations, please refer to previous chapters on Stormwater (2.2.1) and Wastewater (2.2.2), Infrastructure (3).


Photo: Etang Sale lagoon, Reunion Island. © Alexandre Haffner

4.4. FISHERIES, AQUACULTURE AND PEARL OYSTER FARMING

Climate change will affect these activities. However, its impact and the consequences for sensitive natural environments vary depending on the techniques used and the specificities and differences in each overseas territory.

4.4.1. SUMMARY OF INFRASTRUCTURE LINKED TO FISHERIES, AQUACULTURE AND THEIR IMPACT ON THE NATURAL ENVIRONMENT

FISHERIES

For information on infrastructure linked to deep-sea and coastal fishing ports, please refer to Chapter 2.2.

On shore areas of port have dedicated facilities to:

- unloading;
- conservation;
- sales, which can include the following activities:
  - sorting fish complying with European or foreign standards, or to export zones like Japan, for example;
  - auctioning lots to wholesalers and fishmongers;
  - filleting, packing, shipping, and sometimes processing fish.

Infrastructure linked to these activities includes:

- fish unloading docks and facilities for their immediate sale;
- refrigerated warehouses;
- large-scale structures: buildings for filleting, packaging, shipping and sometimes processing fish. These are often located near the docks.

AQUACULTURE

Aquaculture is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants. In the sea, aquaculture is called marine fish farming, but rivers and ponds can also be used.

Different types of infrastructure are required, depending on the type of farming and techniques used:

- shellfish production (including shrimp farming);
- fish farming;
- oyster farming for pearl production;
- seaweed farming;
- sea cucumber farming

SHRIMP FARMING

Mara Hatchery May 2004 NC © Y. Harache, Ifremer 2004

Shrimp are raised in ponds located in coastal areas. Producing shrimp involved three stages:

- a hatchery comprising small often circular covered ponds where nauplii and post-larvae are produced;
- nurseries, composed of shallow ponds for raising post-larvae;
- grow-out ponds, larger ponds (measuring from a few hectares to more than 100 hectares) in which juvenile shrimps develop to marketable size.

The different types of shrimp farming are:

- extensive farming, which accounts for 50 to 60% of farms worldwide. Extensive shrimp farms occupy large areas and use the tide to

Blue Lagoon Farm, may 2004 NC © Y. Harache, Ifremer 2004

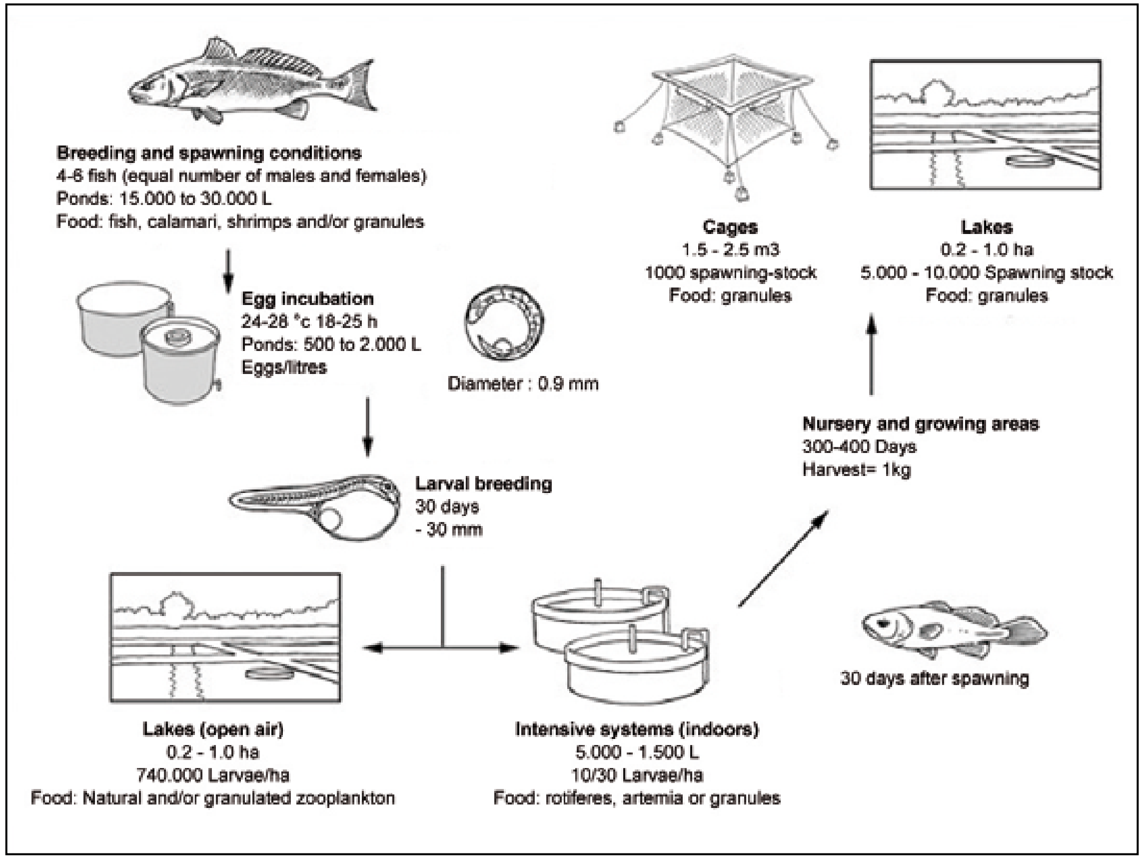
change the water in the ponds and bring food to shrimps;
- semi-extensive farming, covering a surface area of two to 30 hectares; pumps are used to change the water and specific foods are provided; good oxygenation of the water is a prerequisite;
- intensive farms cover a smaller area (0.1 to 1.5 hectares) and require more sophisticated technical equipment and highly qualified personnel. A permanent supply of water is essential to remove waste and to ensure the water is well oxygenated;

The main challenges these farms face are controlling water temperature and salinity as well as pests and diseases at each growth stage.

FISH FARMING

Fish farming can be carried out in fresh, brackish or salt waters. There are two main types:

- pond production in a natural pond, where the fish feed completely or partially on the environment's biological production ;
- intensive production in artificial ponds or cages where fish only feed on food provided by the farmer.



Example of fish production: Fish aggregating devices (Source : FAO)

One example of fish production: sea cages
(Source : FAO)

Intensive fish farming is conducted in fully or partially enclosed spaces (natural, concrete or plastic ponds, giant floating pots or cages, etc.), in freshwater or at sea depending on the species. Food is almost entirely provided by the farmer. Water is constantly renewed by the current in the case of cages. In ponds, water enters via a waterway or in closed circuit farming, the water is recycled, the water is renewed is to ensure it is rich in oxygen and to reduce ammonia. Oxygen can be a limiting factor, mechanical ventilators or pure oxygen injection systems based on liquid oxygen are also often used.

Possible problems include:

- due to the concentration of fish in a restricted space the risk of epidemics is greatly increased. This is a major problem in cages and ponds, but is rarer in lakes;
- high fish density, a fish farming characteristic, is also a source of marine (or freshwater) pollution downstream from ponds or floating cages due to fish faeces, leftover food that is washed away. In France, breeding is strictly regulated.

Fish aggregating devices. Source IRD

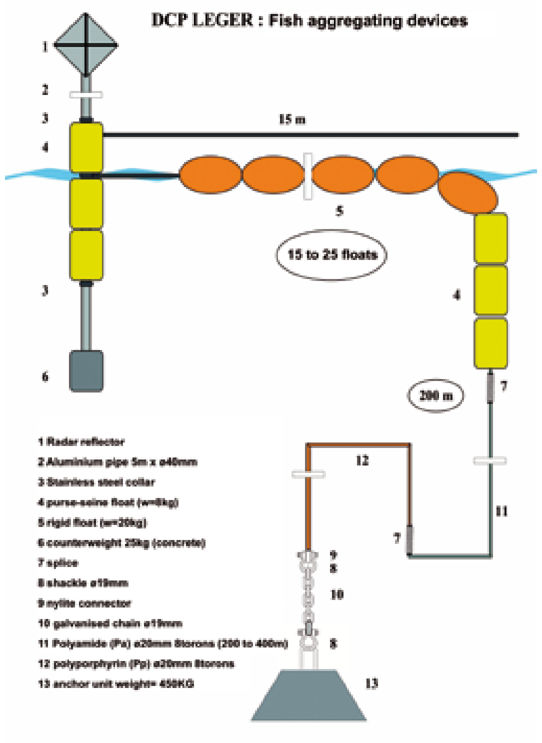


Diagram of a FAD. Source: Marine and Mining Resources Directorate, Pu Fa'ahotu Moana.

Fish aggregating devices (FADs) are natural, floating systems or systems built by man, which attract pelagic fish at certain points in the ocean (artificial reefs are not classified as FADs). They can improve fishing or scientific surface observation of fish ecosystems. The most basic built devices consist of a mooring (several dozen to several hundred meters of lines, anchors and floats). These FADs are usually set up near the coast.

SHELLFISH FARMING

Shellfish farming refers mainly to crustacean or shellfish and is primarily mariculture. It is also a food business, mainly in Asia. The following species are grown: Ostreidae (oysters), Mytilidae (mussels), Pectinidae (scallops) and Veneridae (clams).

This activity is closely linked to the molluscs' life cycle; most farmed species rely on a supply of juveniles captured in the natural environment. Larvae undergo a metamorphosis, and at this stage, they need to be fixed to something. Putting down collectors gives them the appropriate support to obtain a spat (larva). The spat is then placed in structures adapted to the species (bags for oysters, for example) or are scattered. Hatcheries can ensure the production of spat by controlling some of the reproductive stages of the species. The species bred are gastropod grazers or filter feeding bivalves. In the natural environment, the bivalves food is provided by the first link in the food chain: phytoplankton.

Photo © jedecouvrelafrance.com

Mussel growing in Chausey © Thomas Abiven

Other types of shellfish farming produce a sub-product; this is the case of pearl oysters and the aquaculture of decorative shells, which are used to decorate aquariums when they are alive (clams) or to embellish collections when dead (Source IFREMER).

PEARL OYSTER FARMING

This involves the cultivation of pearl oysters by growing them and then grafting them to obtain quality pearls.

Polynesia's oysters, the Pinctada margaritifera variety, produce «Black Tahitian Pearls». Today, pearl oyster farming is an important economic activity in French Polynesia.

Oyster pearl farm in Tuamotu

Source (the lagoon road WIX website)

The different stages of pearl oyster farming are the following:

COLLECTION

Pearl oyster farms obtain their supply using an original larvae capturing technique. All the farms collect spats from just a few atolls. Collectors are made from pieces of polypropylene (used as shade in agriculture), which are strung on a thin rope and produce a support with many crevices, an ideal site for the development of spats intio juveniles.

GROWING OUT

An essential stage in pearl production is growing out the 'pintadines'. In fact, an oyster can only be grafted once it has reached a minimum size and some organs have developed. To grow them out, oyster pearls are placed in baskets or drilled and suspended on strings or in strands.

IMPLANTATION

The principle is implanting a pearl ball called the nucleus and mantle tissue into a section of the pearl oyster with few vital organs, after which the pearl oyster secretes layers of mother of pearl. Immediately after implantation, pearl oysters are placed in baskets for 45 days in order to check the graft success rate. Those that have kept the nucleus are drilled and attached with a nylon cord to a string of 20 oysters. The pearl oyster's growth begins.

SEAWEED FARMING

This refers to the mass cultivation of algae for industrial and commercial purposes. This activity uses both microalgae (phytoplankton) and macro-algae. This type of aquaculture aims to produce food (for humans or as algae fodder), food supplements, veterinary and pharmaceutical products, cosmetics, bio-plastics, fertilisers and even renewable or phytoremediation energy sources (algae fuel, biogas). Recently, algae have been used in nano-biotechnology and genetic engineering. Not all algae species can be cultivated so far, so some macro-algae are still collected at sea or from natural deposits on the foreshore. Others are farmed in «marine fields».

Aigue Marine June 2006. Photp © J. Patrois, Ifremer 2006

Photo-bioreactors. ©IFREMER

Micro-algae can be mass grown in open ponds (lakes, lagoons, natural ponds or artificial structures (e.g. raceway ponds) or in closed photo-bioreactors. Some macro-algae are also grown in raceway ponds under mechanical agitation or intense low pressure bubbling.

OPEN PONDS

The main advantages of open ponds are that they are easy to build, rapidly operational and productive. However, it is difficult to control the cultivation of algae, as they depend on the atmospheric concentration of CO2 and natural brightness. In the absence of mixing, they are not very productive in the long term and are easily contaminated by external parasites or predators.

PHOTO-BIOREACTORS

Photo-bioreactors are expensive to build and more complex to set up, but cultivation can be controlled and they thus enable more sustainable production over time. There are three main types: vertical, tubular and flat-plate bioreactors.

FERMENTORS

Some micro-algae can be grown heterotrophically in the dark, using organic substrates as nutrients. This method of cultivation is used to produce compounds for the pharmaceutical industry.

SEA CUCUMBER FARMING

Sea cucumbers are collected on shallow sea beds and exported in large quantities to Asia (including New Caledonia). Exporting sea cucumbers may be an essential part of developing aquaculture.

Source ULB (Free University of Brussels)

The sea cucumber's reproductive cycle can now be controlled, in particular that of Holothuria

Source Mons University (sea cucumber farming in Madagascar-Madagascar Holothurie SA (MH SA).

scabra, making it possible to obtain a regular supply of juveniles. Production based on juveniles comprises:

- growing to market size either in enclosed spaces onshore or in pens at sea (sea ranching pens);
- growing to market size in the open sea;
- restocking depleted areas to replenish adult stocks, which can then be caught a few years later.

IFREMER (French Research Institute for Exploitation of the Sea) is currently studying joint shrimp and sea cucumber farming.

4.4.2. IMPACTS OF FISHERIES AND AQUACULTURE ON THE NATURAL ENVIRONMENT

FISHERIES

At sea, the main impacts of the fishing industry on the marine environments is overfishing, which alters the balance of the ecosystem, and damage caused by fishing equipment, which can destroy the sea bed and some benthic species. In addition, fishing vessels pollute the water with hydrocarbons.

In port, accidental discharges of pollutants from docks and traffic in the harbour also pollute the water. The main pollutants are hydrocarbons, followed by macro-waste resulting from fishing and organic matter in the form of fish waste and marine organisms trapped in the fishing gear, which are ejected during cleaning or maintenance of the machinery. These pollutants can cause eutrophication of the water in confined areas in the harbour and affect sensitive natural environments near fishing ports.

Fisheries' commercial activities on or near the docks and harbour can lead to macro-waste and pollutants spread on the harbour by high winds and heavy rains. The pollutants are then leached from these areas into the sea.

These different types of pollution could be avoided if port regulations were respected and waste taken to storage facilities available in port activity zones.

AQUACULTURE

The impacts of aquaculture vary greatly depending on the type of activity.

SHRIMP FARMING

Of all types of aquaculture, shrimp farming probably has the highest impact on neighbouring natural environments, especially if the farms are located in or near mangroves and/or coral reefs, which is the case in New Caledonia, where, shrimp farming has the following impacts:

- when the farms are under construction, their size (which can be more than 100 hectares) leads to the destruction of coastal and marine ecosystems within and in the vicinity of the structures;
- when the farms are up and running, very fine sediments from the ponds are transported downstream where they can lead to hyper-sedimentation of any sensitive environments located nearby. In addition, organic matter in the form of food and faeces produced by the farms are excess nutrients in the marine environment and cause eutrophication. The possible risks of marine parasites or diseases should also be mentioned;
- when cyclones bring heavy rains, the dykes around the ponds may be destroyed and/or flooded by overtopping, which can cause hyper-sedimentation of sensitive marine environments.

FISH FARMING

The impacts described above also apply, but to a lesser extent, to coastal fish farming using ponds, as these are much smaller.

The main impact of sea cages is discharge of organic materials (fish food and faeces) which causes organic hyper-sedimentation under the cages and eutrophication in confined environments.

The spread of diseases or parasites from caged species can infect wild fish.

During heavy storms and cyclones, wave energy can drag cages or destroy them and their anchors, causing functional damage to shallow ecosystems, especially in reef flats near the farms.

Individuals may escape into the natural environment when a cage is damaged or an error is committed when handling the species, thus threatening local diversity.

Finally, depending on their location, which is usually in a lagoon environment, some aquaculture facilities can alter the local hydrodynamics.

SHELLFISH FARMING

The impacts of shellfish farming are relatively low as these farms are located in the open sea where currents are usually strong. Pond shellfish farms in French overseas territories are usually small.

PEARL OYSTER FARMING

Oyster pearl farms are a special case, for two Pearl oyster farms are a particular case as they are located in lagoons in French Polynesia. Lagoons are marine public domain, the many requests for permits submitted for this type of business, i.e. to collect oysters, to built and exploit infrastructure, has put significant pressure on lagoons. The impacts of oyster farms are listed below in descending order of importance (source Pae Tai – Pae Uta, PTPU, 2003):

- during production: cleaning, collecting, growing, hatching, harvesting, implanting. The cleaning and collecting stages have the biggest negative impact on the environment;
- impacts on native populations at the site during the construction of anchors for the farms;
- increasing the number of epibionts and their dispersal in the lagoon (via cleaning) and/or to other atolls (during the transfer of oyster pearls). Some epibionts (especially anemones) may have negative effects not only on the development of the oysters, but also on the natural environment;
- during the lifespan of the farm including the construction of farm facilities, sanitation, waste, occupation of the lagoon, scattered settlements. The construction of a farm can introduce plant pests (on construction machinery and during clearing) or animals (rats and cats). The most visible impacts are weeds and a reduction in the sea bird population (due to a reduction in the number of breeding sites);
- a significant increase in ciguatera risks.

SEAWEED FARMING

The impacts are linked to the size of the ponds and the spread of algae, particularly micro-algae, in the natural environment in the case of a technical breakdown, or destruction of the pond and/or of the facilities including tanks being damaged during severe cyclones (very high winds, flooding, submersion). These incidents can cause eutrophication, especially in confined lagoon environments, and enable the expanion of invasive species, which can cover coral formations.

SEA CUCUMBER FARMING

No particular comments can be made on their negative effects, since at the time of writing there only a few farms in French overseas territories. However, when combined with shrimp farms, this activity could have positive impacts (i.e. bioremediation), as sea cucumbers are scavengers (ongoing studies by IFREMER).

4.4.3. FISHERIES AND AQUACULTURE ACTIVITIES, AND THEIR INFRASTRUCTURE IN OVERSEAS TERRITORIES

This chapter makes a number of references and (except when stated otherwise) included figures taken from a report to the French Economic and Social council by the rapporteur Gerard d'Aboville entitled «La pêche et l'aquaculuture en outre-mer" 2007». (in French)

REUNION ISLAND

FISHERIES

Reunion Island's fishing industry has traditional and artisanal origins and began with small-scale coastal fishing, but in the early 1990s, it diversified and established a long-line fishing fleet for pelagic fish around the Indian Ocean. Fisheries in this ocean still have the potential for further development, even though the sector has grown rapidly in the last decade; jobs have doubled, processing and export activities have recently been created and exports from fisheries now take second place after the sugar cane industry.

Small-scale fishing boats go to sea for less than 24 hours and small scale fishing has the largest fleet and the most jobs. Their catch supplies the local market.

Number of vessels in 2005: 245.

Offshore fisheries: coastal and offshore fishing is well developed in Reunion Island which is located at the heart of the Indian Ocean's tuna and swordfish zones; the fleet consists of surface long-liners, in addition to small fishing vessels.

Number of vessels in 2005: 25.

Commercial fishing: Reunion Island also serves as a base for toothfish and lobster fishing vessels in the Southern Territories and French Antarctic.

Number of units in 2005: 10.

Total production (all fisheries): around 10,000 tons.

Fishing ports in Reunion Island

There is an international commercial port near the town of Le Port on the Pointe des Galets peninsula, which is the largest fishing port on the island. Due to the expansion of fisheries, a new industrial dock was built which can unload three large fishing vessels and four long-line fishing vessels simultaneously, plus five moored large fishing and fishery monitoring vessels and 24 moored long-line fishing vessels. The main facilities and activities include:

- unloading and storage warehouses, which comply with European standards;
- processing plants next to the unloading docks;
- skilled floating ship maintenance and repair workers.

The other fishing ports are at Saint-Gilles, Saint-Pierre, Saint-Leu, Saint-Philippe, the dock at Langevin in Saint-Joseph and a marina in Sainte-Rose.

AQUACULTURE

Freshwater fish farms (trout, carp and tilapia) have been operating since 1997. Methods for breeding red drum at sea have been used since 1999. There are 10 fish farms, but only one at sea, in the bay of St. Paul, which currently produces 30 tons of red drum. The hatchery is located to the west of Le Port. In 2012, the total aquaculture output was 122 tons (source: Association for the Development of Aquaculture in Reunion Island (French acronym ARDA). However, this activity recently stopped, at least for the time being, due to attacks by bulldog sharks in the sector.

MAYOTTE

FISHERIES

Fishing is still largely an artisanal activity with the catch destined for household consumption, and traditional methods are still used. There are three types of fishing activities in Mayotte:

- octopus and shellfish fishing from the shore;
- deep-sea fishing (grouper);
- pelagic fishery (tuna, bonitos) by artisanal fishermen, and commercial fishing by French and Spanish tuna purse seiners.

The fleet comprises around 1,000 wooden canoes for lagoon fishing, around 250 polyester boats for offshore fishing around fish aggregating devices (FADs) and 18 modern vessels. There is no port infrastructure dedicated to fishing.

Production: in 2010, commercial fisheries produced 4,300 tons, and artisanal fisheries 1,500-2000 tons.

AQUACULTURE

Aquaculture only began recent in 1999 and is still expanding, it is focused on breeding red drum. Mayotte is the biggest producer of fish-farm fish in French overseas territories, and its four producers produce between 150 and 200 tons per year.

EPARSES ISLANDS

Tuna is the most common species to be caught in the exclusive economic zone (EEZ) of the Eparses Islands. There are around 20 French tuna seiners and 30 Spanish ones.

GUADELOUPE

FISHERIES

Fishing is almost exclusively carried out by artisanal companies. There are three types of fishing activities:

- coastal fishing using saintoises boats, typical Guadaloupian fishing vessels (measuring less than 9 m) with outboard motors. There are about 2,000 of these boats;
- offshore fishing using vessels measuring from 9 to 12 m long which go to sea for a few days, and mainly fish around FADs. There are around 60 of these vessels;,
- deep-sea fishing requires boats more than 12 meters in length. These go to sea for three-week campaigns off the coast of Guyana. There are around six of these vessels.

Sorting fish. Photo: © ML Licari

There is no organised fishing industry in Guadeloupe. In 2005, total production (all fisheries combined) was 10,000 tons. There are 23 main ports, the largest are Beausejour in Desirade and Saint Francois on Grande-Terre.

AQUACULTURE

Currently, three species are bred in Guadeloupe: two freshwater species: Ouasssous (shrimps) and Creole mullet (a red tilapia) and a marine species: ocelli drum fish. All the fish farms in Guadeloupe are supplied by the Pointe Noire hatchery. There are nine aquaculture production sites, grouped mainly around Goyava, Sainte-Rose, Lamentin, Sainte Claude and Pointe Noire.

Production fluctuates between 12 and 20 tons per year.

After total loss of OCEAN farm's stock at Pointe Noire during the OMAR cyclone in 2008, Guadeloupe created a pilot structure comprising offshore submersible cages adapted to artisanal methods to protect fish stock and structures during cyclones. This is the only prototype of it's type in the world, and is now up and running (source: Guadeloupe Union of Aquaculture Producers [French acronym]).

Submersible cage adapted to cyclonic conditions (source Sypagua)

MARTINIQUE

FISHERIES

There are two different types of fishing activities:

- artisanal fishing with skiffs measuring under 8 m, equipped with outboard motors, often around FADs;
- offshore fishing, with five vessels measuring 16 to 25 m, which mainly catch snapper on the plateau off the coast of Guyana. There is no organised commercial industry in Martinique.

Annual production is 5,000 tons. Fishing ports are scattered around Martinique:

- eight departmental fishing ports with facilities for refuelling, maintenance, repair, storage and marketing fish at Anse d'Arlet, Case-Pilote, Port du Diamant, Francois, Grand-Riviere, Marin, Trinite and Vauclin;
- 16 departmental fishing facilities (French acronym APID) with bilge emptying facilities, small buildings and lighting;
- 54 departmental docks.

AQUACULTURE

Aquaculture is currently expanding. Freshwater prawns are being produced and offshore ocelli drum fish and cobia. In 2012, there were four hatcheries and 21 fisheries in protected bays around the coast at Robert, Francois, Vauclin, Sainte-Anne, Anse d'Arlet, Case-Pilote, Belle Fontaine and Carbet.

Production = 89 tons (source SRDAM Martinique 2012)

GUYANA

FISHERIES

After the space industry and gold extraction, fishing is Guyana's third economic activity. But it is currently facing serious problems and production has fallen sharply over the last 10 years. The main resources are shrimp, snapper and white fish. One hundred and forty fishing vessels work all year round, of which 51 are shrimp trawlers.

In 2010 deep-sea fishing yielded around 1,000 tons and coastal fisheries around 1,700 tons.

Fishing ports and infrastructure: the port of Larivot is specialised in shrimp fishing.

AQUACULTURE

Currently, no aquaculture is practised in Guyana, and a study by the 'Regional Project for Aquaculture Development in Guyana' in 2012 concluded that with current techniques, there are no possible sites for aquaculture in Guyana.

FRENCH POLYNESIA

FISHERIES

There are three types of fishing: lagoon, coastal and deep-sea. Fishing ranks third in exports. In 2013,total production was 12,700 tons of which lagoon fishing accounted for 4,300 tons, deep-sea fishing for 5,700 tons (mainly tuna) and coastal fishing for 2,700 tons, particularly around fish aggregating devices (FADs).

- Lagoon fishing, is basically a subsistence activity. A number of traditional fishing techniques are used (rods, nets, bottom lines, pots, spear fishing);
- coastal fishing is carried out by a fleet of 60 bonitiers (10-12 m long) and about 200 poti marara (3 to 6 m long), which are very easy to manoeuvre and thus only need one person (spear fishing, trolling or bottom lines), and mainly work around FADs. In 2007, there were about 400 FADs scattered around all the archipelagos;
- deep-sea fishing (long-lines) began in the early 1990s. The main resource is tuna, which are fished by 70 tuna vessels.

Port infrastructure: the port of Papeete includes a big fishing port with facilities for bunkering ships (ice, bait), storage and marketing fish. The new Port of Faratea (in Taravao, on Tahiti's peninsula) has a logistics platform (surface area: 50 hectares for local and international fishing vessels).

AQUACULTURE

Freshwater and deep-water shrimp, tropical bass, tilapia and some lagoon fish species (mainly trevally and picots) are farmed. Yields vary with the species and are small (in 2005, 60 tons of shrimp were produced, along with 6.4 tons of tropical bass). There are three farms and one hatchery in all. Most aquaculture takes place in Tahiti, Moorea and Bora Bora.

French Polynesia pioneered the eco-aquarium industry (larvae collection and breeding techniques). The industry's objectives are aquarium breeding, ecotourism and managing its resources, in 2004 this activity exported over 50 tons (mainly to the United States).

PEARL OYSTER FARMING

Despite the current crisis, black pearls are one of the key sectors of the Polynesian economy,. Most pearl oyster farms are located in the Tuamotu atolls and the Gambier archipelago, and more recently in the Leeward Islands.

In 2007, the pearl oyster farming involved 830 businesses (collection, farms, and breeding areas) covering a total area of 10,874 ha, of which 712 in Tuamotu, 118 in Gambier, and 60 in the Leeward Islands.

The shells of nacreous molluscs are used for jewellery and cabinet making. In 2006, 2410 tons of nacreous shells, , 100 tons of trochus, and 2.5 tons of Burgau were produced.

Clam breeding experiments are ongoing, particularly for the purpose of replenishing stocks.

NEW CALEDONIA

FISHERIES

Fishing plays a minor role both economically and as a food supply. In 2013, total production was only 700 tons.
There are three types of fishing:

- lagoon fishing (boats less than 10 m long) is for household consumption, using nets, lines, or trolling. However, trochus are harvested to make buttons and jewellery) and sea cucumber for export;
- coastal fishing is done by versatile vessels which can go outside the lagoon and up to 12 miles from the reef (fishing for snapper and pelagic fish); about 200 vessels are used for lagoon and coastal fishing;
- deep-sea fishing is done using long-lines to catch tuna. The fleet has 13 vessels under 20 m in length and 14 ships of over 20 m. Production is 2,500 tons per year.

Port infrastructure is located at Nouville fishing port in Noumea, which serves 20 long-liners. Cold storage units and fish processing and packaging facilities are located behind the docks.

AQUACULTURE

In New Caledonia, fish farming is mainly shrimp farming (2,000 tonnes). It is the second export activity after nickel, but is much smaller. The experimental stage began in 1970, but the shrimp farms only reached industrial scale in 1988 with their first exports. In 2005, 2,400 tons of shrimp were produced. At that time, 18 out of today's 19 private farms were in operation, covering a total area of 674 hectares. The farms vary from 11 ha (family-based farms) to 132 ha (large farms) in size. Four hatcheries produce larvae for all the farms.

Production dropped to 2,000 tons in 2008.

All the farms are all located on the west coast of Grand Terre, most in the Southern Province. Two packaging facilities and two food factories are also in operation. IFREMER actively supports the development of shrimp farming through research and support programmes (source: B. Soulard - IFREMER).

New Caledonia wants to diversify its aquaculture, which today is based on breeding L. stylirostris shrimp. Farming the H. scabra sea cucumber is attracting interest for two reasons: it has a high export value and breeding farms can conduct bioremediation of existing aquaculture environments. As part of the ZONECO programme, the HOBICAL project is working on the technical feasibility and environmental consequences of alternating the culture of L. stylirostris and H. scabra, where the latter are raised in the effluent zone of shrimp farms. The results of this study will improve our understanding in:

- potential bioremediating environments;
- H. scabra nutrition in the natural environment vs. in a breeding farm;
- the future of contrasting ecosystems (Source IFREMER).

Examples of farms:

Blue Lagoon Farm May 2004 © Y. Harache, Ifremer 2004

Montagne Blanche May 2004 © Y. Harache, Ifremer 2004

Examples of hatcheries:

North Hatchery, May 2004 © Y. Harache, Ifremer 2004

Mara Hatchery, May 2004 © Y. Harache, Ifremer 2004

SEAWEED FARMING

A Microalgae Technology Centre (CTMA), is being developed as part of one of the Pole Marin flagship projects. It is called the 'AMICAL' project, is run in partnership with IFREMER, and aims to create an innovative micro-algae production sector in New Caledonia, whose target markets could start with animal feed and human food and proceed to biofuel, as well as algae for the cosmetics and pharmaceutical industries. CTMA has a laboratory, (LEMA), based in Noumea and an application and transfer laboratory, (LTMA), whose construction is underway in Kone. When the LEMA lab started in May 2013, its first task was to select local seaweeds based on their growth potential, and put them in «photo-bioreactors».

Photo-bioreactors. ©Ifremer - Olivier Dugornay

WALLIS AND FUTUNA

FISHERIES

Currently, artisanal fishing is only practised in the lagoon for household consumption (production of around 1,000 tons per year). In 2005, a launching ramp was built north of Futuna. FADs were put in place. Deep-sea fishing is mainly by foreign vessels who catch around 168 tons. A deep-sea fisheries development project is currently under study, along with a project for a fishing port in Halalo. The first tuna long-liner was commissioned in 2010 in Wallis and has caught 39 tons so far. The target is 90 tons/year.

AQUACULTURE

Prawn aquaculture experiments are underway in Futuna.

4.4.4. POSSIBLE IMPACTS OF CLIMATE CHANGE ON DIFFERENT TYPES OF FISHERIES AND AQUACULTURE AND CONSEQUENCES FOR REEF ENVIRONMENTS AND RELATED ECOSYSTEMS

FISHERIES

The increase in sea surface temperature, in salinity, and in primary productivity (even currents) will be combined with an increase in acidification, resulting in a decrease in productivity. This will affect global stocks and cause significant migration, thereby spatially redistributing resources. These impacts will affect both deep-sea and coastal fishing.

Coastal fishing will be affected by degradation of marine ecosystems and of the coast due to climate change, particularly the predicted impacts on coral reefs and mangroves in the tropical zone. Many coastal species spawn and breed in these ecosystems. The problems faced by coastal fishing will probably lead to an increase in overfishing in lagoon areas in some territories, leading to a functional imbalance in these ecosystems (habitat functional degradation of the habitat by fishing equipment, and an imbalance in some fish populations).

The following activities will no doubt have to adapt:

- deep-sea fishing: stock management and monitoring will have to be reinforced, other fishing sites identified, and fishing techniques adapted;
- coastal fishing: there will be a need to reinforce the protection of coastal environments against pollution, to optimise stock management, strengthen the technical adaptive capacity of artisanal fishermen, develop FADs, shift coastal fishing towards deep-sea fishing and aquaculture, or even other activities.

Finally, the rise in sea level and the increase in cyclone intensity probably means that fishing port infrastructure will need to be adapted, and protective structures and buildings linked to fishing will need strengthening. For further details, please refer to chapter *«2.2 Port infrastructure».*

The main impacts will be from more intense cyclones, which may snap anchor and leave FADs adrift.

This will have a limited impact on reef ecosystems and mangroves, although if drifting FADs land, this could cause local functional degradation of reef flats, of the outer slope, or of coral formations by anchors being dragged along the sea bed. (However, the risk is low in view of the depth of the anchors).

AQUACULTURE

SHRIMP FARMING

The major impacts will be linked to:

- the rise in sea level and intensified cyclones which could cause flooding, or destroy pond dykes: deposits of terrigenous particles from the dykes and muddy sediments in the ponds could cause hyper-sedimentation, especially to coral reefs in the vicinity. The organic material in the sediments originating from shrimp farms will also cause eutrophication (algal bloom) in relatively confined environments, which can degrade coral zones. Finally, farmed species escaping into the sea could alter biological balances in nearby sites and possibly introduce parasites or diseases;
- in some regions, the rising sea temperatures and increased heavy rains will alter the characteristics of the water in the shrimp ponds and could affect their growth, if their water replenishing systems are under-sized, overflowing ponds would supply nutrient inputs to nearby coral reefs leading to eutrophication.

FISH FARMING

The same impacts as those mentioned above on shrimp farming will affect onshore fish farming ponds, but to a lesser degree given their smaller size. Freshwater farms will probably have a low impact because they are located farther from the coast and thus also from sensitive marine environments, but they can add to impacts from other sources like watersheds (particularly terrigenous deposits in heavy rains).

Offshore: floating cages will mainly subject to the risk of deterioration and drifting caused by more intense cyclones. These cyclones can cause:

- local functional degradation of coral reefs by beached cages and anchors drifting along the sea bed;
- a possible imbalance in the ecosystem due to farmed species escaping into nearby sensitive environments.

SHELLFISH FARMING

Normally, shellfish farming will have no major impact on sensitive coral environments or mangroves, as it has less infrastructure and can be easily adapted to changes in the environment caused by climate change.

SEA CUCUMBER FARMING

The impacts are the same as on shellfish farming.

PEARL OYSTER FARMING

The changing physical-chemical parameters of the sea due to climate change, particularly temperature and Ph, will affect pearl oysters' growth. Scientific studies are underway to evaluate these risks and to optimise future farm management. The main impacts on breeding and infrastructure in lagoon and reef environments are:

- the rising sea level means the floor heights of farms on stilts will have to be altered or the farms even dismantled and rebuilt. Given the large number of farms, the reconstruction work will cause significant damage at sea and along the coast: turbid plumes and noise during the construction phase, the risk of pollution by hydrocarbons or oils, and the accumulation of macro-waste on the sea bed;
- intensified cyclones may cause partial or total destruction of farms, the accumulation of macro-waste on the sea bed and along the coastline, and detached parts of structures drifting towards sensitive reef zones causing local functional damage.

SEAWEED FARMING

The main risks are linked to the cultivation of micro-algae and the destruction of ponds or tanks by more intense cyclones, which would result in the sudden massive addition of micro-algae to sensitive environments, particularly if these are in confined areas. Eutrophication could then asphyxiate coral formations growing near the affected site.

4.4.5. TECHNICAL RECOMMENDATIONS FOR ADAPTATION

Given the above mentioned problems, we recommend that the actions listed below are carried out by the appropriate services and private operators involved in these projects:

FISHERIES AND PORT INFRASTRUCTURE

The rising sea level and cyclone intensification will no doubt mean that fishing port infrastructure will have to be adapted by strengthening defence structures and altering buildings. For details, please refer to Chapter 2.2. Port infrastructure.

FADS

The intensification of cyclones may require strengthening anchors to prevent them snapping and drifting. If due to climate change, the migratory paths of certain species change, FADs may have to be moved.

AQUACULTURE

SHRIMP FARMING

The major impacts on neighbouring sensitive areas are the risks of flooding and pond destruction caused by the rise in sea level, more intense cyclones and heavy rains, the following recommendations focus on:

First and foremost, a diagnostic survey existing structures. This should include:

- the geomorphologic location of the infrastructure with respect to coral ecosystems and a general presentation of the context of the area identifying the site's current and potential pressures;
- the geometric characteristics of the ponds (dykes, pumping and water evacuation systems);
- the specifications of technical buildings and structures that may cause pollution (e.g. handling equipment, maintenance and storage areas for food products);
- specifications for access to infrastructure on the site;
- a summary of management procedures and possible incidents, especially during exceptional weather conditions and measures that need to be taken;
- analysis of current and potential problems in the design of different types of structures;
- a summary of planned projects to repair, extend or adapt structures;

Our technical recommendations are the following:

Depending on the results of the diagnostic survey of existing infrastructure:

- possible reinforcement of dykes and a change in the size of the ponds' drainage systems (pipe diameters, gradient, outlet dimensions, strengthening pipe fixations, reinforcing buildings and anti-cyclone protections of key infrastructure (storage and maintenance areas);
- possibly review structure maintenance procedures and add more regular monitoring of:
  - dykes and their stability;
  - the status of pipe fixations and landfall sensitive connection points;
  - the condition of buildings and technical infrastructure.

When planning future infrastructure, ensure the most appropriate sites are selected, studies must be undertaken to analyse external pressures on aquaculture infrastructure. Pressure on the watershed due to the risk of increased periods of heavy rains can result in increased river flows and runoff and consequently increased flooding and risks of pond destruction downstream.

The following questions should be asked:

- Are existing water management structures in the area designed to stand up to the foreseeable effects of climate change?
- Should we review the area's flood risk management plans (French acronym FRMP) and adapt drainage structures and settling ponds located upstream from an aquaculture project?

Reflection on planning in the area must take its future development projects and their possible impacts on watershed zones into account by including pressures caused by climate change. The reflection should be undertaken with the appropriate State departments and local services.

In general, analysis of the pressure on aquaculture infrastructure should cover the following points:

- Will pond dykes be able to cope with future pressures from cyclonic swells and the rising sea level?
- Should we review their design? If yes, what defence structures are required? Will some projects in highly exposed sites have to be relocated or even abandoned?
- the size of sea pumping and pond drainage systems must account for the risk of more intense cyclones and rising sea level: the choice of water pumping points will have to be optimised, as will the pipes' gradient, diameter, and choice of materials and fixations.
- the design of operational buildings must take into account the probability of more violent cyclones (risk of flooding and high winds).
- the specifications in the maintenance procedures for the different structures will need to be reviewed.

Further research will be required on a number of issues. The answers to the questions above will probably require:

- additional studies to optimise models of local climate phenomena, to simulate extreme hydraulic situations on and around the structure (hydrology and hydrogeology, calculation of the risk of watershed flooding and overtopping); calculation of possible swells in the vicinity of the structure and measures to improve defence infrastructure;
- optimising observational systems linked to climate change phenomena near the structure (possibly additional measuring equipment in on-site weather stations, tide gauges);

The above recommendations are in «checklist» format to enable the diagnosticians to draft a coherent final document for each type of infrastructure and for all the facilities.

Pearl oyster farming: Workers at a farm in Rangiroa (Source Wikipédia)

FISH FARMING

Here we describe operations that use onshore ponds and offshore floating cages.

Fish farming with onshore ponds, the recommendations are the same as for shrimp farming above.

The main impacts of offshore fish farming using floating cages on sensitive neighbouring environments (coral reefs) are:

- local functional degradation of coral if the anchors of the cages are destroyed and the cages drift in strong cyclonic swells;
- a change in the ecological balance of the environment if farmed species escape when their cages are destroyed.

Our recommendations focus on strengthening anchoring systems (chains and anchors) for existing infrastructure, and setting up submersible floating cages like those recently developed in Guadeloupe (see the SYPAGUA website: http://www.sypagua.com.basicwebreport.net/ in English) when planning future projects. Studies of potential new sites should obviously take pressures created by foreseeable climate changes into account.

SHELLFISH AND SEA CUCUMBER FARMING

The impacts on reef areas will probably be lilited, given their small-scale infrastructure and the fact that these activities will probably remain small in French overseas territories . Consequently, specific recommendations do not appear to be necessary.

PEARL OYSTER FARMING

In addition to the specific impacts of climate change on breeding (studies are ongoing), possible impacts on the lagoon environment would be during works to adapt infrastructure to the rise in sea level and to rebuild farms on stilts damaged by high winds and cyclonic swells.

The recommendations would be:

- for existing farms, check the strength of the structure (stilts, floors and roofs) and reinforce weak points where necessary;
- for future farms, optimise infrastructure by taking future pressures into account:
  - rising sea level (calculate the necessary floor heights);
  - increasing swells and cyclonic wind intensity. Optimise the anchors and the dimensions of the superstructures, reinforce buildings and areas where polluting products used on the farm are stored, optimise management of macro-waste on farms on stilts and on land.
  - protect the terrestrial and lagoon environment during construction (both on land and in the lagoon).

Pearls, Tahiti. Photo © wikipedia

SEAWEED FARMING

The main risk concerning the cultivation of micro-algae is the destruction of facilities by submersion during strong cyclonic swells, high winds and floods. Sudden massive addition of micro-algae in sensitive areas will lead to eutrophication in confined areas.

Our recommendations focus on strengthening the protection structures of these facilities, ponds and superstructures, and are the same as those recommended for shrimp and fish farms, on both existing facilities and future farms, see above.

4.5. AGRICULTURE AND FORESTRY

Here the context here is very different from that of most of the activities discussed above. The risks for reef environments and related ecosystems caused by agriculture are mainly due to damage to crops, and very little or none caused by deterioration of infrastructure (buildings, work tools).

Moreover, agricultural activities - particularly mono crop farming such as sugar cane and banana - have been obliged to diversify to adapt to international market constraint.

Finally, ongoing reflections by the state services concerned on adaptation to climate change will probably recommend crop diversification, with the cultivation of crops that are better adapted to climate change, which will mean changing certain agricultural practices. The consequences for the natural environment depend on these future choices and are difficult to assess at the time of writing. However, the new agricultural strategies should have a positive impact on the natural environment because their key challenges are soil preservation, and the fight against erosion, flooding, and rising salinity.

For these reasons, here we only provide a brief description of:

- agricultural and forestry in French overseas territories;
- their impact on the natural environment;
- possible impacts of climate change.

After which, we will list our main recommendations to limit the possible impacts of damaged crops and forests on coastal and sensitive marine areas.

For more details on sugar cane processing/rum production chains, please refer to the chapters on Stormwater 2.1. and Wastewater 2.2.

Most of the data in this chapter is extracted from the ONERC (Observatoire National sur les Effets du Réchauffement Climatique) report : «Overseas territories facing the challenges of climate change», (in English) addressed to the Prime Minister and Parliament (2012) and the «General agricultural census, 2002; IEDOM, 2011; ISPF, 2011a».

Some of the data on French Polynesia come from a report entitled «The status of the environment in French Polynesia, 2006» by Catherine Gabrie and Heloise You in collaboration with P. Farget.

For more details, please refer to the documents mentioned above and to the Institut d'émission d'Outre-Mer (IEDOM) annual reports (Central Bank for French Overseas Departments) and IEOM (Central Bank for French Overseas Collectivities) for the French Pacific Overseas Collectivities.

4.5.1. AGRICULTURE

Agriculture will be seriously affected by climate change: foreseeable water shortages in some Caribbean Islands and Tuamotus; more intense cyclones and violent tropical rains which can devastate crops, and cause erosion and mudslides; the rising sea level can submerge crops in coastal areas and cause salinisation of the soil and groundwater table.

AGRICULTURAL ACTIVITIES IN FRENCH OVERSEAS TERRITORIES

The importance and type of agricultural activity differ considerably from one overseas territory to another depending on:

- their physical conditions: landscape, soil composition, water resources (rainfall and groundwater), the intensity and frequency of cyclones;

- socio-economic conditions (export-oriented crops and/or food self-sufficiency and traditional crops).

Agricultural activities include exports of mono-cropping systems: sugar cane, bananas in the Caribbean and Reunion Island, rice in Guyana, coconut (copra and derived products) in French Polynesia, Ylang-Ylang in Mayotte, vanilla, tropical fruits and derived products in all overseas territories, and food crops and/or self-sufficiency (market gardening) and livestock farming (cattle, pigs, chickens). Livestock are widespread in New Caledonia, and require a directly linked large-scale activity: the cultivation of forage crops.

Below is an overview of the main agricultural activities and their extent in each overseas territory.

REUNION ISLAND

- 45,035 ha of UAA (utilised agricultural area) accounting for 17.9% of the island;
- main product: sugar cane 59% of UAA;
- secondary products: vegetables, fruit (pineapples, bananas, citrus fruits), livestock breeding (chickens, pigs), pasture and forage crops, vanilla.

MARTINIQUE

- 31,269 ha of UAA, accounting for 28.4% of the island;
- main products: bananas 27% of UAA, sugar cane 9.3% of UAA;
- secondary products: pig and cattle farming, fruit and vegetables.

GUADELOUPE

- 43,535 ha of UAA, accounting for 25.4% of the island;
- main products: sugar cane 33% of UAA, bananas 5% UAA;
- secondary products: vegetables 6.7% of UAA, fruit 1.3% of UAA, livestock farming.

GUYANA

- 25,000 ha of UAA, accounting for 0.3% of the island;
- food crops: cassava, yams, pineapples, bananas, sweet potatoes, maize;
- commercial products: rice, pig and cattle farming.

MAYOTTE

- 20,243 ha of UAA, accounting for 54% of the island;
- main products: bananas, coconuts, cassava, beans, beef;
- commercial products: market gardening, cash crops including ylang-ylang and vanilla.

NEW CALEDONIA

- • 247,878 ha of UAA, accounting for 13.4% of the islands.
- • main products: pasture: 97% of the UAA, cattle farming;
- • secondary products: coconuts, fruit and vegetables, orchards, maize, vanilla.

FRENCH POLYNESIA

- 18,534 ha of UAA, accounting for 5.3% of the islands;
- main products: fruit, copra, nono, vegetables; livestock farming (pigs, cattle, goats and poultry);
- secondary products: food crops, vanilla, coffee, exotic hardwood.

THE IMPACTS OF AGRICULTURAL ACTIVITIES ON THE NATURAL ENVIRONMENT

Besides deforestation which causes biodiversity loss and has a cut-off effect on ecosystems, the main impacts of all agricultural activities on the environment listed below.

POLLUTION BY FERTILISERS AND PESTICIDES

The pollutants penetrate the soil or are transported in runoff to streams, and eventually to the marine environment. Overuse of these pollutants is a serious problem worldwide. Some are very dangerous not only for marine species, but also for human health (e.g. chlordecone in Martinique).

CHLORDECONE

This is an organochlorine insecticide which was widely used in the 1980s to control the banana weevil. It was commercially banned in 1990, but its continued presence in the soil has been measured for decades, and the molecule has been found in some animal and plant food products as well as in water and in the food chain. In Martinique, 56% of rivers are contaminated and the animals (fish and shellfish) in 70% of its streams are contaminated. Fishing or selling any fish and shellfish caught in rivers is prohibited.

Fertilisers supply nitrates and phosphates to the aquatic environment where they cause eutrophication in lagoons.

The impact of pesticides on coral reefs is still not well understood; however, herbicides are clearly very dangerous due to their effect on seagrass meadows and symbiotic algae in the hermatypic corals which form coral reefs.

These pollutants are particularly widespread in banana mono-crop systems as the crop suffers particularly from soil parasites (nematodes and weevils) requiring extensive use of pesticides and frequent replanting.

HYPER-SEDIMENTATION PHENOMENA

This phenomenon is linked to soil erosion. Its prevalence depends on the topography, type of soil, methods of cultivation and specific climatic conditions (cyclones and heavy rains) in tropical zones. The addition of terrigenous particles to the marine environment originating from agricultural erosion or earthworks on slopes are a major cause of destruction of the fauna found in fringing coral reefs.

Certain crops intensify erosion including:

- pineapple when grown on steep slopes like in Moorea in Polynesia;
- bananas, due to its method of cultivation which requires frequent replanting;
- some large goat, sheep and cattle farms have a major impact due to trampling and intense grazing of vegetation;
- fires due to poorly controlled slash-and-burn: repeated burning prevents vegetation regrowth;
- construction of roads and access roads to agricultural land is also a source of erosion when the slopes are not stabilised, and drainage systems are undersized or non-existent.

Generally speaking, the lack of land stabilisation and/or the absence of settling basins downstream from agricultural land is a source of sometimes massive additions of sediments to lagoons.

New rational crop strategies such as crop rotation and anti-erosion measures are being developed to limit these pollution problems and land degradation.

SPECIFIC REMARKS ON THE CULTIVATION OF SUGAR CANE

Sugar cane is a perennial with a well-developed root network that tends to reduce soil erosion. Rainfall has limited impacts due to its large leaf surface area and thick layer of dry leaves on the ground, which also reduces rainwater runoff. It has deep roots, which stabilise the soil and improve soil structure. The environment in sugar cane plantations also stimulates micro-flora.

Sugar cane consumes a lot of water and nutrients, but is nevertheless able to grow in poor or very acidic soils. It is usually planted on large mechanised farms located in flat areas. As it has beneficial influences on the soil it is used in many countries - particularly in South America – where sugar cane is grown on slopes that are not suitable for most other crops.

The commercial cultivation of sugar cane also has some negative impacts on the environment. The demand for sugar and ethanol resulted in an increase in sugar cane monoculture, leading to extensive deforestation in the Amazon, for example. Elsewhere, wetlands that were considered unproductive were drained and irrigated to grow sugar cane fields, thereby destroying these fragile environments and polluting the water with pesticides and fungicides.

POSSIBLE IMPACTS OF CLIMATE CHANGE ON DIFFERENT TYPES OF CROPS AND THE CONSEQUENCES FOR REEF ENVIRONMENTS AND RELATED ECOSYSTEMS

THE MAIN IMPACTS ARE:

- **Increased water shortage and droughts:** this is a risk in all the overseas territories, but will be exacerbated in areas with higher temperatures and lower rainfall (West Indies, Reunion Island, New Caledonia). It will be worst where there is an increase in intra and inter-annual rainfall variability. This will become an economic issue for crops which require a lot of water like sugar cane, bananas or melons. Droughts could also affect livestock farming and food crops, especially in New Caledonia, the West Indies and Guyana. The impact on coral reefs will be due to the degradation of certain crops resulting in unstable soils followed by the restructuring of damaged crop fields. This could require earthworks, which are likely to result in terrigenous particles being transported downstream and eventually into lagoons.
- **increased soil erosion:** on the one hand, due to droughts which reduce soil quality in deforested areas (New Caledonia, Mayotte) and on the other hand, due to an increase in heavier rains (French Polynesian islands, for example) or in the intensity of cyclones in the West Indies. These risks will increase hyper-sedimentation phenomena in marine environments and coral reef degradation, particularly in fringing reefs.
- **More diseases and parasites:** particularly in crops which are already affected, such as banana. Market gardening and plantations of other fruit are also threatened as they are very sensitive to parasites and diseases, especially in Reunion Island and the West Indies. Possible overuse of pesticides to control parasites will affect the natural environment.
- **Agricultural production will be affected by extreme weather conditions (cyclones, heavy rains, droughts):** if these weather conditions become more frequent this could increase agricultural losses, especially in the West Indies and Reunion Island and, to a lesser extent in French Polynesia where cyclones are rarer. In New Caledonia, the rising temperatures and lower rainfall could cause more bushfires.
- **Destruction of crops by soil salinization or sea submersion and erosion:** These specific coastal phenomena could accumulate and gradually damage some farms located in coastal plains on atolls (market gardening, melons, coconuts, tarot, yams) and even destroy them during the cyclone seasons, for example.
  - Degraded coral reefs and mangroves and the resulting decrease in protection against wave energy, will increase risks for crops located on the shoreline.
  - In Guyana, the possible increase in erosion will continue the destruction of coastal rice fields.

TECHNICAL RECOMMENDATIONS FOR ADAPTATION

A set of technical, agronomic, organisational and institutional actions would address some of the structural problems the agricultural sector is currently facing in French overseas territories, which would reduce its intrinsic vulnerability and facilitate its adaptation to climate change pressures. These solutions fall in the categories "sustainable agriculture" or "smart agriculture" (FAO 2010), whose aim is to support productivity and crop resilience (Angeon, 2011), and soil conservation.

Only a brief list of the possible major recommendations is given below, as a lot of work has already been done in the agricultural domain and it is preferable to refer directly to the documents: useful guidelines on agricultural adaptation in the National Adaptation Plan to Change Climate (NAPCC) and Rural Development Programme (RDP) reports written in the framework of the European Agricultural Fund for Rural Development (EAFRD) for the overseas territories, available on the «agriculture. gouv.fr» website. These documents provide a list of recommendations on how to optimise crops and protect the environment, in each French overseas territory.

THE MOST IMPORTANT RECOMMENDATIONS ARE :

Technical solutions

To get round the risk of water shortage, it will be essential to increase the volumes of water available using a range of technological methods (catchments, dams, harvesting stormwater) and to increase storage (reservoirs) and supply (pipe networks).

These methods will require major construction works including earthworks with major risks of terrigenous particles ending up in the marine environment (for recommendations, please refer to Chapter 2 on Stormwater management).

To fight against soil erosion, a number of techniques can be used depending on the type of crop: mulching, maintaining or developing anti-erosion devices in steep terrain (hedges, facines, walls, etc.); reducing soil preparation to preserve organic matter, which decomposes rapidly in the tropics.

Agronomic solutions

It will be important to facilitate the transition to more suitable agronomic systems able to cope with climate changes; to promote more environmentally friendly agricultural and livestock farming practices that reduce soil erosion and pollution.

N.B. Organisational and institutional solutions are not taken into account in this document.

Precise detailed technical descriptions can be found in the different documents mentioned above.

4.5.2. FORESTRY

This paragraph, like the previous one, is based largely on the above-mentioned report: «Overseas territories facing the challenge of climate change» report. Whole paragraphs are quoted from this document.

Forests depend on climate, so the expected increases in rainfall, temperature, air humidity and solar radiation will affect their distribution, composition, structure and health. Loss of biodiversity and resources is expected along with a decrease in the climatic (CO2 storage) and environmental (soil and coastal protection) services they provide.

The impacts of climate change on forests will thus have a significant negative impact on the marine environment, particularly on sensitive areas such as coral reefs. Soil degradation will cause massive erosion and consequently the addition of large quantities of terrigenous sediment to reef flats.

Here, we only mention terrestrial forests, as mangroves were discussed in the introduction to this document.

BRIEF DESCRIPTION OF FORESTS IN OVERSEAS TERRITORIES

The extent of primary forests varies depending on the physical conditions (landscape, climate, soils) and anthropogenic pressures. The largest natural forests in French overseas territories are found in Guyana and mountainous tropical islands where, in general, they cover larger surface areas than reforested ones.

IN OVERSEAS TERRITORY DEPARTMENTS

Table 7, on the next page, lists the characteristics of forests in French overseas departments.

Overseas territory	Total surface area of forest (in ha as a % of the territory)	% of natural forests and main types in overseas territories	Public management (ONF) in ha and as a %	Private management in ha and as a %	Forestry production (m^3)
Guyana	8.000.000 ha 95%	95 % of equatorial forest	- 8.000.000 ha >99%	<1%	72.000 m^3 Limited to a coastal strip
Martinique	47.000 ha 43%	26 % hygrophilous, mesophilic and xerophytic forests	15.741 ha 33%	31.023 ha 67%	2.136 m^3
Guadeloupe	69.000 ha 40%	/	38.223 ha 55%	31.000 ha 45%	
Reunion	120.000 ha 48%	39 %,Semi-arid, hygrophilous, mesophilic and ericoide	100.515 ha 83%	20.000 ha 17%	4.298m^3
Mayotte	1.120 ha 3%	3 %, hygrophilous, dry thickets	Public ONF-CEL		

Table 7: Data from the ONF and National Forest Inventory 2007-2011.

Cane fields and houses in Petite-Ile, Reunion Island (Source : Wikipédia)

«Guyana's forests are threatened by fragmentation from roads (RN2), illegal gold mining developments (mercury pollution), poaching and strong demographic pressure. On islands, primary forests globally cover a limited surface area, but this is variable (see table below). On some archipelagos, they have virtually disappeared (Mayotte, Austral Islands in French Polynesia) and some dry forests and lowland semi-arid forests are threatened. A decline in total forest area can be observed and natural forests in particular, when compared to forestry perimeters. Reforestation projects are not compensating land clearance. Forest loss has induced their degradation because roads and trails have been built which have encouraged the spread of invasive species».

IN THE FRENCH PACIFIC ISLANDS

«Deforestation has condemned most forests and facilitated the spread of invasive species. New Caledonia's rainforests and dry forests have been replaced by savannah which now covers 40% of the island. In dry years, these are threatened by fires, like in 2002-2003 where 48,000 ha of rainforest was destroyed. However, the savannah is similar to forests in that it plays a role in protecting against soil erosion, but it is threatened by overgrazing and fires».

- On Wallis and Futuna, primary forests cover only 10% of the land area and continue to be threatened by anthropogenic pressures and invasive species.
- In French Polynesia, the natural forest covers 140,500 ha (40% of the land area), forest plantations cover 9,500 ha (2.7% of the land area) over 62% of which is Caribbean pine, 4.3% is protected hardwood, 4% is exotic hardwood and 50,000 ha (14.2% of land area) are coconut plantations. One of the initial objectives of plantations in this territory was protecting the soil against natural erosion. Protected hardwoods (3,500 ha) are mainly found in the Leeward and Austral Islands planted to reduce the erosion on their steep slopes. Caribbean pine was also planted to protect some areas of the Marquesas.

CURRENT THREATS TO FORESTS AND THEIR IMPACT ON SENSITIVE MARINE ENVIRONMENTS

Overall, the above data reveals a significant loss of natural forest, despite protection and reforestation efforts. There are several reasons for this loss:

- anthropogenic pressure: urbanisation, road building, agriculture, livestock farming, mining (in New Caledonia), logging;
- fires;
- invasive species.

Padza in Mayotte (source: Carole and Guillaume)

Yet, forests provide major services in the form of soil protection, regulating the flow of rivers, carbon storage, maintaining groundwater tables, wood production, and agricultural resources.

Their impact on sensitive marine environments, particularly coral reefs, is mainly soil erosion which causes degradation and hyper-sedimentation in lagoon environments due to leaching of the soil, particularly from excavated steep slopes, of alterite ferralitic type. The significant impact of the erosion of padza and a high silt level in its lagoon and certain fringing reef flats is visible in Mayotte and New Caledonia faces the same problems.

Although forest exploitation is limited, it can have a major impact on the environment through its mills where sawn wood is treated against mould, rot, termites and other wood-eating insects. The treatment involves soaking with insecticides-fungicides, and hazardous products (chromium, copper, arsenic) whose use requires special precautions are used in the vacuum pressure treatment, particularly the treatment of residues in the tank bottoms. However, this type of pollution can be avoided if handling and product management procedures are respected.

THE POSSIBLE IMPACTS OF CLIMATE CHANGE ON THE DIFFERENT FORESTS AND CONSEQUENCES FOR REEF ENVIRONMENTS AND RELATED ECOSYSTEMS

Added to existing pressures, changing climate parameters will have a significant impact on the distribution, composition, structure and health of forests in the inter-tropical zone. A reduction in the extent of forests and biodiversity loss is expected, both of which will diminish ecological services provided by the forest.

First, rising temperatures will result in a shift of bio-climates and their forests to higher land.

Forests that are unable to find refuge in the highlands due to anthropogenic pressures, and rain and cloud forests on summits will be in danger of disappearing, with a high risk of biodiversity loss.

Second, droughts, fires and deforestation destroy forests which are then replaced by savannah, particularly forest edges.

Human pressures on certain forest areas will accelerate and more intense cyclones will encourage the spread of invasive species. These species will reduce the forest's capacity to adapt as well as forest biodiversity.

Forest degradation will affect the soils making them more fragile and easily erodable thus increasing terrigenous additions to lagoons and consequently causing hyper-sedimentation and asphyxia in sensitive environments (coral reefs and seagrass beds).

TECHNICAL RECOMMENDATIONS FOR ADAPTATION

PROTECTING A FOREST'S GOOD ECOLOGICAL STATUS. A balance must be found between protecting and sustainably managing the forest resource.
«In the island territories, it is urgent to protect threatened forests that are currently open to anthropogenic pressures, but also to improve the management of protected forests as they are deteriorating from the spread of invasive species or human activities. The challenges are to protect not only threatened or potentially threatened plant formations, but also the soils, whose erosion is likely to be accelerated by climate change.

Different management strategies can be put in place from creating wilderness areas to setting up collaborative management projects to protect the forest from threats and anthropogenic pressures. Maintaining a forest's good ecological status is the NAPCC (National Adaptation Plan to Climate Change (for the Overseas territories) aim».

Sugar cane and banana fields in Martinique. (Source : Wikipédia)

Mango harvest on a plantation in Reunion Island. (Source : Wikipédia)

Particular attention needs to be paid to forests located on steep slopes, as their degradation in periods of heavy rain can have a significant impact (landslides, mudslides) on property and populations located downstream. This in turn, will affect the marine environment through hyper-sedimentation, deposits of blocks and rubble and of macro-wastes on fringing reef flats. An inventory should be made of forest areas at risk, including a diagnosis of the measures that should be carried out or reinforced, particularly FRMPs, along with concrete recommendations for the protection and stabilisation of these sites.

MAINTAINING OR ESTABLISHING PROTECTED AREAS FOR FOREST FORMATIONS AND ENDANGERED SPECIES

Critical areas of forest which require protection need to be identified and we recommend creating ecological corridors, particularly for mountain forests.

REDUCE THE RISK OF FOREST FIRES AND ENHANCE FOREST RESPONSE CAPACITY

IMPROVE KNOWLEDGE ON ADAPTIVE FOREST MANAGEMENT

The need for knowledge has already been identified by NAPCC forest actions. In view of current uncertainties on the impacts of climate change on forest ecosystems, it is important to reinforce monitoring of climate and ecosystem changes, particularly to identify which species are the most resistant to rising temperatures and water shortage. The scientific community also recommends further studies on the vulnerability of forest systems to today's pressures to improve our knowledge of forest functioning. This is a precondition for more accurate modelling of regional and local climate change (Ohlson et al., 2005).

The development and implementation of adaptive management of forest ecosystems is crucial; today's uncertainties should not delay action.

INCREASE THE COMMERCIAL PROFITABILITY OF FORESTRY SECTORS

This will not only help by providing wood, but also protect soils.

Fakarava, French Polynesia. Photo: © Franck Mazéas

CHAPTER 5

5 / CONCLUSIONS AND RECOMMENDATIONS

The aim of this guide was to review all major infrastructures and activities along the coasts of French overseas territories, to analyse their risk of degradation due to current and future climate change, and to deduce the impacts these changes could have on neighbouring sensitive natural coastal and marine environments, such as coral reefs and mangroves.

The aim of our analysis was to make recommendations to limit the risk of degradation in order to preserve these ecosystems, not only for their intrinsic wealth but also for the services they provide in protecting coastal areas.

The table below summarises the main impacts of climate change on infrastructures and their effect on coral reefs and related ecosystems.

Reef fish, Fakarava. Photo: © Franck Mazéas

Table 8: Major impacts of climate change on infrastructures and their effect on coral reefs and related ecosystems.

Impacts of CC on infrastructures : o: zero; +: low; ++: medium; +++: potentially high. **Possible consequences of the impact of climate change on coastal infrastructures for coral reefs and related ecosystems** (red): high risk of consequences, (orange): medium risk of consequences (yellow): low risk of consequences	'Low rate' of continuous and permanent climate change					Climate change 'high rate' of violent periods			
	Rise in temperature °C	Average rise in sea level	Increase in annual rainfall	CO and CO2 concentrations in the sea	Ocean acidification	Exceptional tides	High rainfall in certain periods	High winds and associated waves	Low pressure & cyclone frequency
Sea protection structures	o	+++ (yellow)	o	o	o	+++ (orange)	o	+++ (red)	++ (yellow)
Stormwater management structures	o	++	+	o	o	+++	+++	+	+
Wastewater treatment structures	o	++	++	o	o	+++	+++	++	+
Drinking water supply structures	o	++	o	o	o	+	++	o	+
Airport infrastructure	o	+++ (yellow)	+ (yellow)	o	o	+++ (orange)	++ (yellow)	+++ (orange)	+
Port infrastructure	o	+++	o	o	o	+++ (red)	o	+++ (red)	+
Road infrastructure	+	+	o	o	o	+++ (orange)	++ (yellow)	++ (yellow)	++ (yellow)
Energy related infrastructure	o	o	o	o	o	++ (yellow)	++ (yellow)	++ (yellow)	+
Tourist infrastructure	+	+	o	o	o	+++ (red)	+++	+++ (red)	++ (yellow)
Industrial/artisanal infrastructure	o	++	o	o	o	+++ (red)	++	++ (yellow)	+
Housing	+	+	+	o	o	+++ (orange)	+	+	+
Fisheries, aquaculture, pearl oyster farming	+	+	+	o	o	+++ (red)	+	+++ (red)	++
Agriculture	++	o	+	o	o	++	++	++ (yellow)	++ (yellow)

For each type of infrastructure, the table below lists the necessary components of a diagnosis on existing infrastructure and adaptation measures required to limit the deterioration of existing and future infrastructures.

DIAGNOSIS OF EXISTING INFRASTRUCTURES

Documents to be provided and issues to be addressed	Facts to be taken into account	Graphic documentation
Technical report on the infrastructure concerned	Focus only on structures likely to have an impact on coral reefs and their ecosystems	• Technical specification sheet • Map of the area including the watershed zone (scale 1:25 000)
Geomorphological description of the site	Information on the watershed: hydrological and hydrogeological conditions, wetlands including mangroves and coral reefs in the vicinity of the infrastructure	• Geomorphological map of the the watershed and the marine environment (including lagoons) • Hydrological and hydrogeological maps
Any plans that apply to the area concerned	Coastal Management Plan, Water Development and Management Master Plan, General Plan, Flood Risk Management Plan, ...	Appropriate maps
Information on the area directly linked to the infrastructure: description of the different structures present	• Geometric characteristics and nature of materials • Characteristics of potentially polluting structures (depots, workshop reservoirs, etc.) • Characteristics of drainage and sanitation systems	• Plans and longitudinal and cross sections highlighting low-lying areas • Plans and sections of structures
Summary of management and maintenance procedures for the above structures	Description of maintenance operations and their frequency	
Analysis of any previous incidents: pollution, flooding, sea submersion, deterioration of the structure due to extreme weather conditions	• Description of weather conditions during the event: rainfall, swells, wind, etc. • Description of the resulting phenomena: flooding, accumulation of sediments, deterioration of structures, dispersal of pollutants. Description of measures implemented • Overview of incidents and feedback/ conclusions.	Maps of the events, graphic, diagrams, photographs

Table 9: Components of a diagnostic survey of existing infrastructure, adaptation measures to limit deterioration of existing infrastructure and to prevent damage to planned future structures.

Wooden dugout canoe on Longoni beach. Photo: © B.M.

RECOMMENDATIONS FOR CLIMATE CHANGE ADAPTATION MEASURES

Areas concerned and stakeholders	Possible impacts	Adaptation measures
Areas located outside the perimeter of the infrastructure • Analysis of pressures followed by discussions with the appropriate local services: • Equipment • Urban planning, Environment	**At the scale of the watershed** • Analysis of the risk of more intense cyclones (higher winds and heavier rains), to foresee possible impacts: erosion, falling rocks, landslides, mudslides, transport of terrigenous particles, flooding **At the coastal scale** • Analysis of the risk of sea submersion and the cumulative effects of flooding originating either from the watershed or sea submersion • Include in the analysis planned future development and test different scenarios.	• Planning documents must include the possible impacts of climate change (select development scenarios that limit impacts on infrastructure and on the environment in the upstream watershed, the coastal plain and in the marine environment). • Check planning documents and include possible pressure on infrastructure. • Make technical recommendations for the management of flood risks, the prevention of terrigenous deposits, pollution; Analyse existing systems and the possible need for resizing structures that control river flows and sediment loads in the watershed zone, Measure dimensions of stormwater and sewage systems.

Areas concerned and stakeholders	Possible impacts	Adaptation measures
Zone affected by the infrastructure Analysis of the likely effects of climate change on infrastructure in collaboration with the team responsible for the management of the infrastructure	• Analysis of the risk of more floods and/or sea submersion and their impacts: •Deterioration of protection structures; • Analysis of the risk of pollution of sensitive environments (coral reefs, mangroves) by leaching in sealed zones and settling ponds and/or malfunctioning drainage and sewage structures. • Analysis of the impact of intensification of cyclones on infrastructures, particularly in areas where toxic products are stored.	**Measures** • Reinforcement of the network of weather, hydrological and hydrogeological observatories on site and in the vicinity (piezometers, weather stations, tide gauges, ... • Reflection on the current design of protection structures and possible measures to reinforce or modify the structures. • Strategic analysis of the need to abandon sites or relocate infrastructures. • Rank key sites to be maintained and protected in the French overseas community. • Review the status of embankments and roads taking the possibility of extreme weather conditions, rising temperatures and more heavy rainfall into account. • Analyse current stormwater drainage and sewerage structures with a view to resizing. • Analyse the status of structures used to store oil and warehouses containing pollutants and with a view to reinforcing them if required; • Check the drainage system and maintenance procedures
Analysis of the area neighbouring the structure in the case of specific problems, in collaboration with the team responsible for the management of the infrastructure and environmental specialists	**For example, avian risks** Analysis of risks involved in expanding wetlands or of the appearance of new wetlands near runways, linked to heavier rainfall and as a result, a higher risk of the presence of birds near runways	**Identify measures to limit increasing avian risks:** e.g. draining the site; alter surveillance protocols.

The main points of the technical analysis should enable each overseas territory to define its own strategy and an adaptation plan to ensure all the infrastructure concerned will be able to withstand the effects of climate change:

- define priority actions;
- prioritise actions and estimate construction costs;
- draw up a work schedule;
- create a local group to monitor the progress of the action plan and its technical and scientific aspects in collaboration with the appropriate central technical departments (particularly to monitor changes in climate parameters and to analyse feedback from extreme weather conditions).

5.1. TERRITORIAL PLANNING IN BROADER TERMS

These plans, as well as adaptation plans to climate change, are obviously the main reference documents and they should include reflection on how to protect coral ecosystems faced with probable climate change.

The progress of such plans varies considerably depending on the statutory specificity of each French overseas territory or collectivity. Indeed enforceable «land law» (and development documents) vary considerably depending on the local authorities in each overseas territory and range from an almost complete lack of reflection and formal planning (the situation in Wallis and Futuna) to restrictions similar to those in mainland France for communities in overseas Departments.

The list of existing documents (in French) below is not exhaustive, as the situation is constantly evolving):

In French overseas territories that are Departments (DOM) one can rely on the former SDAU Master Plan for Urban Development (French acronym SDAU), Territorial Coherence Scheme (French acronym SCOT), Land Use Plan (French acronym POS), (Local Urban Planning Scheme (French acronym LUP), Risk Preparedness Plan other than «flooding» (French acronym PPRx), but also on the State's Public Maritime Domain concept and on water and coastal laws when planning and implementing protective and adaptive measures for coral ecosystems.

New Caledonia:
The situation in New Caledonia is not the same, as the power of the French State is gradually being handed over because of their organic land law and Noumea agreements. One can rely on the Territorial Coherence Scheme, Land Use Plan and Local Urban Planning Scheme if these are available, but the Public Maritime Domain is provincial. French national water and coastal laws do not apply, which hinders effective management. Certain documents have been drawn up for Risk Preparedness Plans (particularly for slope issues), but at the time of writing they are not enforceable as Risk Preparedness Plans because mainland France's official documents have not yet been approved by the New Caledonian Territorial Congress.

In French Polynesia:
The General Planning Scheme, General Development Plan and Detailed Development Plan are territorial plans. There is a Public Maritime Domain which is respected to varying degrees depending on the archipelago concerned, but French water and coastal laws do not apply in French Polynesia.

In Wallis and Futuna
There is no land registry; no urban planning documents and only traditional laws apply.

Since each territory has its own specificities, which can change considerably over time, after preliminary studies on developments in coastal areas, we recommend selecting existing structures that can be adapted, existing structures that cannot be adapted and need to be relocated, rebuilt, or demolished, and new structures which require adaptation or will be easy to adapt. The statutory thresholds, limits and building conditions concerning these structures will need to be defined according to the land law.

5.2. IMPORTANCE OF RAISING AWARENESS ABOUT CLIMATE CHANGE

Studies on human geography (S. Bantos) and coastal anthropology (E. Worliczek) in the Pacific revealed that indigenous people in Oceania do not believe they are directly concerned by the impacts of climate change. Only a very small proportion of the population believes the information provided by scientists and the media. Most people believe the changes in the environment they can see are part of the natural cycle and not a climate disruption, while for many, if the climate is going to change, it will be elsewhere and not at home.

A ninth grade survey in Sada, Mayotte, April 2008. Photo: © M. Allenbach

Given the extent of the coral areas in French overseas territories and the importance of this ecosystem in the subsistence economy for most inhabitants, it is crucial to raise their awareness of the risks implied by current climate dynamics. To achieve this objective, we must rely on people identified as referents in these communities, especially traditional authorities and by educating their children who are the best disseminators of information to parents.

Certain impacts of change climate, such as rising sea levels, are hardly visible to people and many policy makers are more concerned with short-term issues than with implementing policies to address impacts in the coming decades. At the very least, they need to be made aware of the risks, so they take measures to avoid making the many mistakes (e.g., extracting beach aggregates or destroying fringing reef flats) which amplify the natural trends that are already weakening the coral ecosystem.

5.3. IMPORTANCE OF MONITORING CLIMATE CHANGE INDICATORS

It is crucial to dispose of validated data on the impact of climate change on the coral ecosystem.

This is why, as part of its national action plans, IFRECOR set up climate change observatories to ensure the same approach to protecting coral ecosystems is used by all the French overseas territories concerned. This study, which was conducted in collaboration with the French National Observatory on the effects of climate change (French acronym ONERC) identified eight key indicators: surface sea temperature, status of reefs, changing coastline, ocean acidification, changes in the sea level, extreme weather phenomena, changes in coastal vegetation, coastal aquifers and saltwater intrusions. The data we collected will help understand, quantify, and qualify the facts.

The data will also help disseminate precise information to populations and decision-makers on what is happening throughout their territories and not just give a general picture. Unquestionably, ongoing climate changes will have a long-term impact on coastal ecosystems, especially on the coral ecosystem, as it is very sensitive and particularly endangered. This particular ecosystem thus needs to be closely monitored to minimise expected impacts as far as possible, to foresee the measures that will need to be taken, as and when warnings are issued by the observatories.

Up to date information from these observatories can be found at http://servlet.univ-nc.n/series/IFRECOR

5.5. QUALITY APPROACH TO SUSTAINABLE DEVELOPMENT

Environmental risks are now a key parameter that should be incorporated when identifying the most suitable approach for planning development projects, whether for infrastructure, an activity, or housing. Environmental risks must be identified and analysed and become an integral part of project management, in terms of sustainable development and three other major axes: environmental, economic and social implications. If the project involves an overseas territory in which this fragile ecosystem is present, the impacts of the project on the particularly sensitive coral ecosystem should naturally be included in the quality process.

Project holders and contractors must be able to understand the overall risks and take them into account in a broader approach under a project's quality assurance. These risks should therefore be integrated when drawing up Schemes for Quality Assurance Organisation Plans (French acronym SOPAC), and then in the Quality Assurance Plans themselves.

International certification

- Leadership in energy and environenmental design (LEED) www.usgbc.org
- Building Research Establishment Environnemental Assessment Methodologie (BREEAM), www.breeam.org

Interactions with, and the influences and impacts of any project on the environment have to be strictly controlled. These parameters must be checked at each stage of the project construction, maintenance and operation, rehabilitation and renovation and finally, demolition at the end of its service life.

Lagoon, New Caledonia. Photo: © Franck Mazéas

APPENDICES

SUMMARY

APPENDIX 1

1.1 / BACKGROUND ON CLIMATE

Source: Meteo-France - Extracts use intentionally simpler terms and/or are paraphrased

For billions of years, climate has been changing due to natural external factors, such as the distribution of land and ocean masses, astronomical parameters, variability of solar radiation, volcanic activity, or because of factors that are an integral part of climate systems, particularly interactions between its component parts (the atmosphere, the oceans, continental surfaces, the ice shelf, ice sheets, etc.).

But this should not be interpreted to mean that most increases in global average temperatures observed since the middle of the 20th century are not due to higher concentrations of greenhouse gases resulting from human activities, primarily the use of fossil fuels.

The IPCC report points out that over the past 1,300 years, there have been warmer 50 year periods than the last 50 years of the 20th century. These warmer periods were probably due to natural causes. But even if this is true, it does not exclude human activities as the main factor (over 9 chances out of 10) influencing climate changes since 1950, compared to natural factors.

In the decade 1999-2008, the planet's average air surface temperature increased and, according to the World Meteorological Organisation's estimates for 2009, the 2000-2009 period was warmer than the previous decade, which was already warmer than the 1980s. However, it cannot be not excluded that the global average temperature (and indeed the temperature in mainland France) may decrease in the coming decade due to the natural variability of the climate system.

But this hypothesis does not call into question the reality of recent climate changes which will have to be analysed throughout the century.

CO_2 is not the only element that regulates our climate, but does affect it by increasing the greenhouse effect, even though the main greenhouse gas is water vapour. Other factors also explain climate change.

CO_2 is the most important all the human based greenhouse gases because of its higher concentration and long atmospheric lifetime: about 20% of CO_2 emitted today will still be in the atmosphere in a thousand years' time.

Atmospheric concentrations of CO_2 have also varied greatly over the ages and have sometimes been much higher than today's (for example, 60 million years ago concentrations were perhaps 10 times higher than today and of course even higher in the planet's primitive atmosphere.
However, the average concentrations observed today (around 388 parts per million by volume) have probably not been exceeded in the last 650,000 years.

The beginning of global warming which transformed the ice age into an interglacial one preceded the increase in atmospheric concentrations of CO_2 by several centuries. The transition to an interglacial period (the last occurred about 20,000 years ago) was due to changes in the the circular orbit of the Earth around the sun and variations in the obliquity of our planet's rotational axis.

However, this does not mean that there is no cause and effect link between changes in the concentration of CO_2 and changes in temperature.

Let's take the example of one of the many effects of the climate system: a cause, in this case global warming linked to the changes in the Earth' orbital parameters, produces an increase in CO_2, which in turn amplifies the initial warming effect. Without this positive effect, it is impossible to explain the scale of global warming between the last glacial age 20,000 years ago and the climate today (globally an average of 4 to 7 °C).

Regular neutron measurements in several different sites around the world indirectly help deduce that cosmic radiation, which varies according to the 11-year solar cycle, has not significantly increased over the last 50 years. Even accepting the existence of a mechanism that links cosmic rays to climate (not yet demonstrated), it does not explain variations in average temperatures over the last half century.

The most comprehensive studies use information drawn from observations to attribute recent climate changes to different sources. They are mainly based on variations in temperature, space and solar radiation over time and knowledge gained on the climate system through climate modelling. None of these studies show that solar variability has played a significant role in global warming since 1950.

Among the publications discussed in the IPCC report, the authors of one article concluded that climate models may underestimate the magnitude of the simulated response of climate to solar variability. But, despite this unconfirmed hypothesis, the same authors concluded that climate change caused by greenhouse gas emissions is the main indicator of the second half of the 20th century.

The first studies on this subject began 15 years ago. They were based on a comparison between observations and climate simulations that took into account every possible source of climate changes over the course of the 20th century (solar variability, volcanic activity, greenhouse gases and particle concentrations originating from human activities). In recent years, these studies have multiplied and incorporated a wider set of parameters. The IPCC experts' conclusions on the role human activities play in recent global warming are based on an analysis of the scientific literature.

National Meteo-France climate data is available on request for research and training purposes. Weather data is shared globally. Ninety-five percent of the data used to study changes in global temperatures is available in the «Global Historical Climatology Network's» database at the National Climatic Data Center in the USA.

But raw data cannot be used without preceding scientific work. In fact, jn addition to regular checks to eliminate incorrect data (erroneous transcripts, a malfunctioning sensor), the analysis of weather patterns requires the correction of measurement biases (linked to a given observation method) and consistent long data series (to be able to identify and correct the effect of changing the location of measurement sites, or changing sensors).

APPENDIX 2

2.1 / CENTRE FOR MARINE AND FLUVIAL TECHNICAL STUDIES METHODOLOGY FOR THE PROTECTION OF STRUCTURES

Strategic recommendations for the protection of structures (2012) (©National Strategy for integrated costal management: towards relocating activities and assets: 2012-2015 Action Plan) and http: //webissimo.developpement-durable.gouv.fr/IMG/pdf/C_11-01_cle2a11a2.pdf are as follows:

1. Define a spatial scale for the diagnosis of physical hazards, urban planning choices and operational planning.
2. Draw up 10, 40 and 90 year planning schedules that take the evolution of physical phenomena into account and, based on cost-benefit analysis, consider the possibility of relocating activities and assets as an alternative to stabilising the coastline in the medium and long-term.
3. Set up a coherent joint territorial management unit to cope with risks of coastal erosion and sea submersion, and appoint a leader in charge of a territorial development plan who shall monitor its implementation by players selected for their respective skills.
4. Justify the choice of coastal operational planning by carrying out cost-benefit and multi-criteria analyses.
5. Only in densely inhabited zones or areas of national strategic interest, consider protection projects which change the natural state of the coastline or design them so that in the long-term these activities and assets can be relocated elsewhere.
6. Use adaptive coastal management techniques in areas with average density (random urbanisation) or predominantly agricultural areas.
7. Protect and restore coastal ecosystems (wetlands, sand dunes, mangroves, coral reefs, etc.) as they play an important role in reducing wave energy and thus in limiting the impact of coastal erosion on activities and assets.

AXIS A . DEVELOP COASTLINE OBSERVATIONS AND IDENTIFY EROSION RISK AREAS IN ORDER TO PRIORITISE PUBLIC ACTION

ACTION 1. ESTABLISH A NATIONAL NETWORK TO OBSERVE AND MONITOR THE COASTLINE RELYING ON REGIONAL PLAYERS

Issues

Observation and monitoring of the coastline implies establishing a network of players to produce or receive data to ensure coherent data collection, frequency and interoperability.

When several initiatives are undertaken by different organisations at different scales, there will be a wealth of data covering long periods, but the data may be ignored or insufficiently exploited due to the lack of sharing, and of joint coordination of long-term initiatives. Moreover, the resulting data will not enable a regional and national overview of local actions and of their results.

Many French coastal hydrology and sedimentology studies have been conducted in recent decades as part of coastal management planning schemes, but beyond their final report, they have not been exploited; this has led to the accumulation of insufficiently exploited data.

SUB-ACTION 1.1
A national network of coastline observatories

Establishing a national network of coastline observatories is a necessary approach within the «Inspire 1» directive framework. This network will rely on ongoing initiatives and ensure the interoperability of future data and wider access to these data and metadata. This action will:

- establish a national observation and monitoring network of coastal evolution relying on regional players;
- establish national coastal erosion mapping and identify erosion risk areas.

SUB-ACTION 1.2
Update sedimentology catalogues

Capitalising on existing data will enable an overview of our knowledge of coasts. Referent sedimentology catalogues were already published in the 1980s and updated in 2015.

To implement these actions, several conditions have to be met:

- identify expertise at the appropriate level, at least at the regional administrative level;
- ensure sustainable funding, particularly in the context of future State-Region 2014-2020 projects and future European programmes;
- define and implement rules to share data and metadata;
- develop new tools to access data;
- develop bathymetry and high resolution topography.

ACTION 2. START NATIONAL COASTAL EROSION MAPPING AND IDENTIFY AREAS AT RISK OF EROSION

Issues

No national mapping exists to identify areas where there is both erosion and a high number of activities and assets using a common methodology, despite the fact such mapping is a precondition for prioritising public action.

Neither does France have reliable national indicators to monitor the long-term evolution of the coastline. Such indicators would make it possible to identify areas where erosion is a problem and to prioritise public financial commitment to planning and to future engineering works. National coastal erosion mapping could be carried out using the Eurosion (www.eurosion.org) consortium's data and existing local data.

SUB-ACTION 2.1
National coastal erosion indicators

A reliable national indicator will be defined to qualify coastal erosion, based on the average speed of erosion, and known topography and bathymetry to distinguish high, medium or low erosion risk areas. This indicator should be used to record coastal erosion in mainland France and in French overseas territories at a scale of 1/100 000.

SUB-ACTION 2.2
Identifying erosion risk areas

Data on land use will also be collected to identify erosion risk areas (dense urban centres, industrial and port activities whose proximity to the sea is essential, transport infrastructure, etc.).

Achieving these two sub-actions by the end of 2013 will help to diagnose the level of sharing and validation on a local scale, at the level of the government Prefect and senior Commissioners as well as local authorities in affected overseas territories.

ACTION 3. DEFINE LOCAL EROSION RISK STRATEGIES IN AREAS AT RISK

Issues

Identifying high erosion risk areas which are also of real importance only makes sense if it culminates in a shared and forward-looking perception of the issues and prioritises public action in these areas, particularly in terms of reflection, planning and operating facilities to manage the coastline.

Under the «flooding2» directive, Local flood risk management strategies are developed in collaboration between the local authorities in the overseas territories concerned, the State, and local services, and are then approved by prefectural decree. Even if the local strategies are not applicable in planning documents, they provide concrete territorial projects adapted to flood risks (including sea submersion) and erosion.

SUB-ACTION 3.1
Local erosion risk strategies

In erosion risk areas, it is important to ensure that coastal erosion is taken into account in local strategies, under the flooding directive, and that they can also be applied in sectors where coastal erosion is the only problem. These local strategies will help establish guidelines and ensure coherent urban planning, conservation of natural areas, management of the public natural maritime domain, risk prevention and facilities to manage coastal erosion.

SUB-ACTION 3.2
Coherent erosion and submersion policy

In erosion risk areas, it is important to ensure that coastal erosion and general management issues, are included in funding already available for flood prevention (French acronym PAPI) and rapid submersion (French acronym RSP) action plans to ensure coherent public policy.

In the first half of 2012, a coastal programme was developed covering integrated coastal risk management (sea submersion and estuary flooding, erosion, etc.). It incorporated coastal rapid submersion action plans and recommendations as part of the national strategy for integrated coastal management.

ACTION 4. IMPROVING THE USE OF URBAN PLANNING AND RISK PREVENTION TOOLS

Issues

Coastal management operations have, so far, mainly been studied from an ad hoc and very technical perspective, firstly, the actual physical phenomenon itself at the scale of a sedimentary basin, and then at the scale of human activity planning (urban planning documents of the SCOT and LUP type). The successful operation of the facilities depends on their inclusion in planning and urban spatial planning documents and risk prevention plans. However, managing these policies falls under the responsibility of overseas territories and collectivities or under the responsibility of the State, or in some cases, both. Reinforcing coherent, continuous public action integrating spatial planning, urban planning, and risk prevention (particularly coastal erosion risks), calls for a shared perception by communities in overseas territories and the State. In this situation, the evolution of the coastline and hence the physical phenomena involved in coastal erosion have to be taken into account in the sustainable spatial planning of territories at different scales. The spatial and urban planning documents should clearly address the subject and set out appropriate guidelines on the use (development/protection) of these territorial areas, and, if appropriate, provide relocation options for certain activities.

SUB-ACTION 4.1
Develop shared guidelines

The State and communities in overseas territory must strive to develop a shared diagnosis of physical changes in the phenomenon, to clarify related issues, as well as measures to be taken to cope with such changes. Clarifying the issues should be based on coastal erosion and sea submersion maps. Where appropriate, these diagnosis and action guidelines can be incorporated in a local spatial planning and sustainable development directive, depending on the scale of erosion or submersion phenomena, and if the area concerned is suitable.

SUB-ACTION 4.2
Incorporation in coherent territorial schemes

This shared diagnosis must lead to selecting a number coastal operational facilities. These options must be taken into account in existing or pending territorial coherence schemes (French acronym SCOT). When the boundaries of sedimentary units extend over several SCOTs, it is essential to work in partnership to ensure technical and geographical consistency in the choice of operational developments in the two SCOTs concerned.

SUB-ACTION 4.3
Increase the 100 m coastal strip

It must be possible to increase the 100 meters coastal strip through the local urban planning (LUP) scheme when sensitive environments or coastal erosion warrant it (Article L146-4 of the Urban Planning Code). This would make it possible to delimit areas that are potentially subject to erosion for a specified time period as well as accounting for the impacts of climate change. This additional zone must have the same restrictive building criteria as the 100 m strip. At the least, the area facing a high risk of erosion must be included in the additional strip in the coastal risk prevention plans.

SUB-ACTION 4.4
Flood risk management plans

The floods directive put in place flood risk management plans and the latter should take coastal erosion into account.

SUB-ACTION 4.5
Issuing building permits

Building permits for projects likely to endanger public safety will be refused if there are no approved risk prevention plans (RPP), as they are in high risk areas (article R 111-2 of the Urban Planning Code).

SUB-ACTION 4.6
Multi-hazard prevention plans

Multi-hazard risk prevention plans (RPP) (sea submersion, estuary dynamics, coastal erosion) should also be drafted, under the current review of sea submersion RPPs. These should outline local strategies for prevention, protection and backup measures in planning developments.

In high hazard areas, risk prevention plans should take into account the coastline's movement and receding coastal phenomena during storms, in accordance with the revised national coastal RPP guidelines. By 2100, the impacts of change climate must also be taken into account when drawing up guidelines for building infrastructure and superstructure, and large urban planning developments in order to limit their vulnerability in potentially affected areas.

SUB-ACTION 4.7
Operational support for local players

Methodological support will be provided to clarify local players' respective skills and help them select their operational developments for coastal management: operational files will be drafted. The flooding and sea submersion cost-benefit analysis methodology will be finalised and adapted to coastal erosion. Each player should implement and be responsible for his/her actions, based on their skills and with the help of other institutional players.

ACTION 5. DEVELOP MANAGEMENT PROCEDURES FOR THE PUBLIC MARITIME DOMAIN

Issues

Integrated coastal management goes hand in hand with coherent management of the public maritime domain. In practice, permission to occupy the public maritime domain does not necessarily take into account the overall impact of planning developments on the evolution of the coastline. As a result, the public maritime domain's management terms need to be implemented in line with the principles of current national integrated coastal management strategies.

SUB-ACTION 5.1
Evaluating occupancy authorisations

It will be necessary to solve the issue of public domain occupancy authorisations for sea defences by doing an impact study at the scale of a sedimentary cell, a cost-benefit analysis, in compliance with local erosion risk management strategies under sub-Action 3.1 and, where applicable, implementing compensatory measures.

SUB-ACTION 5.2
Appropriate project holders

It will be necessary to solve the issue of authorisations to build sea defences to authorised trades union associations, public institutions, overseas territorial communities or their associations.

SUB-ACTION 5.3
Dismantling structures

Provision should be made to dismantle obsolete sea defence structures, or structures that have adverse effects, once their public maritime domain occupancy authorisation has expired, and to manage the associated financial resources.

For these three sub-actions, a circular was drafted by the Ministry of Sustainable Development in 2012.

ACTION 6. RAISING THE AWARENESS OF THE POPULATION ON COASTAL RISKS BY MEANS OF AN INFORMATION CAMPAIGN

Issues

The format of information on coastal risks respects their knowledge giving objective, but rarely targets the general public. It is essential to raise the populations' awareness of these risks more effectively by using more appropriate communication tools.

Several ways to raise the populations' awareness of coastal risks will be developed:

- the national sea and coastline observatory's website is exclusively dedicated to coastal area issues, which could be further developed around coastal risks and adapted for the general public;
- Days dedicated to the sea, these are held annually with celebrations in every French region;
- Communication campaigns should be included in the rapid submersion plans;
- Information campaigns should be implemented by local officials, as they are responsible for informing their local populations.

AXIS B. MOVING TOWARDS A SPATIAL PLANNING RECONSTRUCTION CONCEPT

Given the risk of erosion or sea submersion in an affected area, four coastline management options are cited from the «Coastline Management» book (Quae Publishing, 2010):

- monitoring natural evolution where no action is needed;
- limiting intervention by following natural processes;
- moving back existing buildings behind a new natural or man-made line of defence;
- leaving the coastline as it is.

To develop a concept for coastline management , the 4 above options could be combined into two strategic options:

- **Strategic Option A:** leaving the coastline as it is. This option is possible in high risk areas or of national strategic interest, as long as it agrees with this strategy's principles and recommendations. It may be a temporary solution, as relocation is inevitable in the long term.
- **Strategic Option B:** prepare and implement relocation of activities and assets. Depending on the issues and the level of erosion, this option could be monitoring natural changes, limiting interventions or moving back in the short term. In any case, we must work with the coastline's natural evolution by adapting land use to natural dynamics.

ACTION 7. PREPARE TO RELOCATE ACTIVITIES AND ASSETS AS PART OF TERRITORIAL RECONSTRUCTION DYNAMICS

Issues

Relocating activities and assets means, in the short or long term, moving them further inland to a safer distance from the risks they incur from the sea.

New coastline management measures have been tested in several European Union countries including in the United Kingdom, and in France.

Case studies of these sites have underlined the importance of cost-benefit analysis when the cost of a standard protection structure, made of riprap, by far exceeds the value of assets to be protected in the long term (i.e. during the assets' service life). Thus, relocating these activities and assets can be a real budgetary opportunity in the long term.

SUB-ACTION 7.1
Call for relocation projects

With the view to increasing the relocation of activities and assets, experiments have been conducted through call for projects to «relocate activities and assets exposed to coastal risks». The aim of this approach is to give support to local players, first and foremost communities in overseas territories, and to prepare the implementation of spatial reconstruction. Setting up these types of territorial projects cannot be accomplished only at the municipal level; it must be done inter-communally and in the end, by transposing them into SCOTs.

Alongside calls for projects, the financial terms of implementing the relocation of activities and assets were studied in 2012.

SUB-ACTION 7.2
Writing a national methodology guide

A national guide will be drafted, based on the knowledge acquired through the experimental calls for projects, to provide conceptual elements (identifying situations where relocation is preferable, taking into account medium and long term prospects) and a methodology (using existing legal tools, identifying funding or compensation opportunities, stages of implementation, evaluating long-term costs and benefits, enhancing long-term benefits, communication and dialogue, rehabilitating newly released coastal areas, etc.). To complement this guide, it will be important to clarify the public institutions property (EPF) mandate in order to prepare the relocation of the activities, in the case of a public project holder (a community) with the commitment to purchase the land for a development project: legally, EPF can only act in development operations under the urban code (Article L 300-1).

ACTION 8. ECOLOGICAL ENGINEERING INNOVATIONS

Issues

In the framework of the new national biodiversity strategy (2011- 2020), objective 7 – including the preservation of biodiversity in economic decisions - and objective 8 - developing innovations for and through biodiversity - economic players in the general ecological engineering sector are directly concerned. Furthermore, the Grenelle Agreement commits France to move towards an economy that is less dependent on fossil fuels, greener, and more economical with natural resources. This change highlights the importance of a new «Green economy» which offers the opportunity to develop eco-technologies able to meet these requirements. In this context, the Ministry of Sustainable Development has launched a supportive approach for strategic green economy sectors. One of the priorities is financing technological showcases and demonstrators in order to highlight the technical nature of the sector and to reinforce its innovative capacity. Developing innovative techniques for coastline management has been identified as a key working axis.

Call for ecological engineering projects

A call for innovative projects in ecological engineering of coastal and sea environments was launched in July 2011. One of the key aspects of these projects was to enhance ecological engineering actions in the coastal strip, for example by proposing buffer zone replanting projects to protect inhabited coastal erosion areas, new eco-technological processes to stabilise beaches or dunes or reduce the swell effect onshore.

The expected projects were research demonstrators designed to test a specific technology in real operating conditions. The research demonstrator's scale makes it possible to move up from the laboratory scale to validating technologies at industrial scale.

The list of winners is available on the Ministry of Sustainable Development website, under Construction, urban planning, planning and natural resources / Water and Biodiversity / Biodiversity / National Strategy for Biodiversity / Zoom on call for projects / call for projects results.

AXIS C. SPECIFY FINANCIAL INTERVENTION TERMS

ACTION 9. IDENTIFY FUNDING PRINCIPLES FOR INTEGRATED COASTAL MANAGEMENT

Issues

Funding sea defences is the owners' responsibility. Article 33 of the Law on the drying out of marshes passed on 16th September 1807 states that «when it comes to building dykes to protect against the sea, or navigable or non-navigable rivers, streams or torrents, the need will be initiated by the Government and the expenditure incurred by the private protected properties, as long as such works are in the public's interest; except where the Government believes it is useful and just to grant aid out of public funds». This law gives owners of waterfront property the responsibility of bearing the cost of defence structures, but the State can intervene financially. The State makes the decisions concerning the need for works (gives authorisation to do defence works), but the waterfront owners bear the financial burden.

An amendment to this Law was passed on 21st June, 1865 stating that residents could join syndicated associations to build defence works or to manage them. Therefore, any waterfront owner is legally obliged to participate in funding a sea defence structure. Ultimately, the successive amendments to this legislation granted communities in overseas territories financial aid for these types of works. Article L 211-7 of the Environment Code stipulates that: « communities in overseas territory and their associations and mixed unions established under Article L 5721-2 of the Overseas territory communities General Code are entitled to use articles L151-36 to L151-40 of the Rural Code to carry out a study, to build and operate any works, actions, structures or facilities that are of public interest or urgent, within the existing spatial planning and water management scheme, if there is one, and to [...] defend against flooding and the sea; [...]».

Articles L 151-36 to L151-39 of the Rural Code allow a community project holder to pass the financial burden on to owners who need the work to be done.

SUB-ACTION 9.1
State's funding priorities

The State shall define the conditions and criteria governing its financial intervention. For sea submersions, the framework is provided by the rapid submersions plan. For coastal erosion, State funding focuses on high risk erosion areas, those of major public interest and on technical, flexible and reversible coastal management, which could include the relocation of activities and assets in the medium to long term. In addition, the financial terms for their relocation need to be clearly identified.

SUB-ACTION 9.2
Regional commission institutions

Regional commissions will be established directly linked with basin committees to together study requests submitted as rapid submersion plans, for PAPI (Program of Actions and

Preventions against Floods) and applying for coastal management funding from the Ministry of Sustainable Development. (© National Strategy for integrated coastal management: towards the relocation of activities and assets: 2012-2015 action plan).

http://www.developpement-durable.gouv.fr/IMG/pdf/12004_Strategie-gestion-trait-de-cote-2012_DEF_18-06-12_light.pdf

Key commission groups in mainland France:

PARLIAMENTARY REPRESENTATIVES

Ministry of Ecology, Sustainable Development and Energy

- General Directorate for Spatial Planning, Housing and Nature Conservation (water management and biodiversity);
- Housing, Urban Planning and Landscape Management;
- General Directorate for Risk Prevention;
- Regional Environment Directorates, Spatial Planning and Housing in Languedoc-Roussillon and the Pays de la Loire;
- Departmental Directorates of Charente-Maritime's territories and sea, English Channel and Pas-de-Calais;
- Centre for marine and fluvial technical studies.

Ministry of Agriculture and Food

- General Directorate for Agricultural policies, Food and Territories;
- Delegation to Spatial Planning and Regional Attractiveness

NATIONAL ASSOCIATIONS OF ELECTED COASTAL REPRESENTATIVES

Socio-professional representatives

- Permanent Assembly of the Chamber of Agriculture;
- National Shellfish Committee;
- French Federation of Insurance Companies

The State's public institutions

- Geology and Mining Research Institute (French acronym BRGM);
- Coastal and Lake Shore Conservation Authority;
- National Forestry Office;
- Naval Hydrographic and Oceanographic Service;
- Brest, Caen, and Montpellier Universities.

APPENDIX 3

3.1 / AIRPORTS IN FRENCH OVERSEAS TERRITORIES

Airport	Town	IATA	ICAO	Altitude in meters	Observations
971 Basse Terre Baillif Airport	Basse-Terre	BBR	TFFB	18	Minimal use
971 Grand-Bourg Airport	Marie-Galante	GBJ	TFFM	5	
971 La Desirade Grande Anse Airport	Grande Anse - Île de La Désirade	DSD	TFFA	2	Minimal use
971 Les Saintes Terre de Haut Airport	Les Saintes	LSS	TFFS	7	Minimal use
971 Guadeloupe Airport, Pôle Caraïbes	Pointe-à-Pitre	PTP	TFFR	11	
971 Saint-François Airport	Saint-François	SFC	TFFC	3	
972 Martinique Aimé Césaire International Airport	Fort-de-France - Le Lamentin	FDF	TFFF	5	
973 Félix Éboué International Airport	Cayenne	CAY	SOCA	9	
973 Grand-Santi Airport	Grand-Santi		SOGS	56	Minimal use
973 Kourou Airport	Kourou		SOOK	11	Minimal use
973 Maripasoula Airport	Maripasoula	MPY	SOOA	114	Minimal use
973 Saint-Georges-de-l'Oyapock Airport	Saint-Georges-de-l'Oyapock	OXP	SOOG	11	Minimal use
973 Saint-Laurent-du-Maroni Airport	Saint-Laurent-du-Maroni	LDX	SOOM	5	
973 Régina Airport	Régina	REI	SOOR	6	Minimal use

973 Saül Airport	Saül	XAU	SOOS	224	Minimal use
974 Gillot Airport	Saint-Denis	RUN	FMEE	20	
974 Pierrefonds Airport	Saint-Pierre	ZSE	FMEP	18	
975 Saint-Pierre Airport - Pointe-Blanche	Saint-Pierre	FSP	LFVP	9	
975 Miquelon Airport	Miquelon	MQC	LFVM	3	
976 Dzaoudzi-Pamandzi Airport	Dzaoudzi	DZA	FMCZ	18	
977 Gustaf III Airport - Saint-Barthélemy	Saint-Barthélemy	SBH	TFFJ	15	Minimal use
978 Grand-Case Espérance Airport	Saint-Martin	SFG	TFFG	7	
986 Futuna Pointe Vele Airport	Leava - Futuna (île)	FUT	NLWF	6	
986 Wallis Hihifo Airport	Mata-Utu - Wallis (île)	WLS	NLWW	24	
987 Ahe Airport	Ahe		NTHE	2	
987 Anaa Airport	Anaa	AAA	NTGA	3	
987 Apataki Airport	Apataki	APK	NTGD	2	
987 Aratika Nord Airport	Aratika		NTKK	5	
987 Arutua Airport	Arutua	AGR	NTGU	3	
987 Bora Bora Airport	Bora Bora	BOB	NTTB	1	
987 Faaite Airport	Faaite		NTKF	2	
987 Fakahina Airport	Fakahina	FHZ	NTKH	0	
987 Fakarava Airport	Fakarava	FAV	NTGF	0	
987 Fangatau Airport	Fangatau	FGU	NTGB	3	
987 Hao Airport	Hao	HOI	NTTO	3	
987 Hikueru Airport	Hikueru	HHZ	NTGH	2	
987 Atuona Airport	Hiva Oa	HIX	NTMN	3	Minimal use
987 Huahine Airport	Huahine	HUH	NTTH	2	
987 Katiu Airport	Katiu		NTKT	3	

987 Kauehi Airport	Kauehi		NTKA	2	
987 Kaukura Airport	Kaukura	KKR	NTGK	1	
987 Makemo Airport	Makemo	MKP	NTGM	5	
987 Manihi Airport	Manihi	XMH	NTGI	3	
987 Mataiva Airport	Mataiva	MVT	NTGV	3	
987 Maupiti Airport	Maupiti	MAU	NTTP	2	
987 Moorea Airport	Moorea	MOZ	NTTM	4	
987 Napuka Airport	Napuka	NAU	NTGN	4	
987 Niau Airport	Niau		NTKN	3	
987 Nuku Hiva Airport	Nuku Hiva	NHV	NTMD	1	
987 Nukutavake Airport	Nukutavake	NUK	NTGW	4	
987 Tahiti Faa'a International Airport	Papeete	PPT	NTAA	3	Mixed
987 Puka Puka Airport	Puka Puka	PKP	NTGP	2	
987 Pukarua Airport	Pukarua	PUK	NTGQ	6	
987 Raiatea Airport	Raiatea	RFP	NTTR	7	
987 Raivavae Airport	Raivavae		NTAV	2	
987 Rangiroa Airport	Rangiroa	RGI	NTTG	2	
987 Reao Airport	Reao	REA	NTGE	3	
987 Rurutu Airport	Rurutu	RUR	NTAR	4	
987 Takapoto Airport	Takapoto	TKP	NTGT	4	
987 Takaroa Airport	Takaroa	TKX	NTKR	4	
987 Takume Airport	Takume		NTKM	2	
987 Tatakoto Airport	Tatakoto	TKV	NTGO	4	
987 Tetiaroa Airport	Tetiaroa	TTI	NTTE	2	
987 Tikehau Airport	Tikehau	TIH	NTGC	4	
987 Mataura Airport	Tubuai	TUB	NTAT	3	
987 Tureia Airport	Tureia	ZTA	NTGY	0	

987 Ua Huka Airport	Ua Huka	UAH	NTMU	0	Minimal use
987 Ua Pou Airport	Ua Pou	UAP	NTMP	37	Minimal use
987 Vahitahi Airport	Vahitahi	VHZ	NTUV	451	
987 Aratika Perles Airport	Aratika		NTGR	53	
987 Totegegie Airport	Totegegie	GMR	NTGJ	35	
988 Tiga Airport	Tiga	TGJ	NWWA	39	
988 Poé Airport	Bourail		NWWB	2	
988 Waala Airport	Île Art	BMY	NWWC	93	Minimal use
988 Koné Airport	Koné	KNQ	NWWD	7	
988 Moué Airport	Île des Pins	ILP	NWWE	97	
988 Koumac Airport	Koumac	KOC	NWWK	13	
988 Lifou Wanaham Airport	Lifou	LIF	NWWL	28	
988 Nouméa Magenta Airport	Nouméa	GEA	NWWM	3	
988 Poum Malabou Airport	Poum	PUV	NWWP	2	
988 Maré La Roche Airport	Maré	MEE	NWWR	42	
988 La Foa Oua Tom Airport	La Foa		NWWT	30	
988 Touho Airport	Touho	TOU	NWWU	3	
988 Ouvéa Ouloup Airport	Ouvéa	UVE	NWWV	7	
988 Nouméa La Tontouta International Airport	Nouméa	NOU	NWWW	16	Mixed
988 Canala Airport	Canala		NWWX	2	

3.2 / AIRPORT VULNERABILITY TO CLIMATE CHANGE

Technical Information from the Technical Civil Aviation Service (TCAS), CS 30012 31 Avenue du Maréchal Leclerc – 94385 BONNEUIL-SUR-MARNE CEDEX. In Toulouse: 9, avenue du Docteur Maurice Grynfogel - BP 53735 to 31037 TOULOUSE CEDEX

ONE OF THE AXES OF THE NATIONAL ADAPTATION PLAN TO CLIMATE CHANGE

The study entrusted to TCAS is part of the National Adaptation Plan to Climate Change (NAPCC), whose aim is to prepare France to cope with the effects of global warming. The NAPCC includes a section on transport systems; the French Directorate General for Civil Aviation is in charge of the air transport section.

The study was conducted in 3 stages

- Stage 1: identifying key climatic hazards, their potential impacts on airport infrastructure and specific technical references.
- Stage 2: developing a methodology to evaluate airport vulnerability and to test it.
- Stage 3: apply the method to representative platforms to assess their vulnerability.

CLIMATIC HAZARDS AND THEIR IMPACT ON AIRPORTS

Several climatic hazards were selected from different sources (Intergovernmental Panel on Climate Change, synthesis of climate scenarios, January 2011, led by J. JOUZEL under the NAPCC, Meteo-France data, etc.).
The potential impacts of these climate hazards were identified based on feedback from operators and from the status of existing structures.

Three «issues» were selected as they characterise which parts of an airport could suffer from the impact of climate change: infrastructure (manoeuvring area, access roads, parking lots, etc.), buildings (terminals, control tower, etc.), and operations.

IMPACTS ON INFRASTRUCTURE

- Take-off distances can be affected in some cases and runways need to be extended or an aircraft's take-off weight needs to be reduced;

- accelerated wear of airport runways and taxiways;
- weakened soil foundations, deterioration of manoeuvring zones, shrinking/swelling clay particles;
- less demand for de-icing products, less pollution and resulting soil degradation;
- in the case of flooding in manoeuvring zones, the construction of protections is required;
- collapsed coastal infrastructure;
- non optimal runway orientation due to a change in the direction of prevailing winds.

IMPACTS ON BUILDINGS

- higher temperatures inside terminals and control towers;
- less need for heating;
- increased need for air conditioning;
- fire risks, closure of airports bordering forests;
- flooding, submersion of coastal terminals;
- shrinking/swelling clay particles causing cracks in buildings ;
- destruction of frangible or mobile elements (passenger boarding bridges);
- partial and total destruction of buildings.

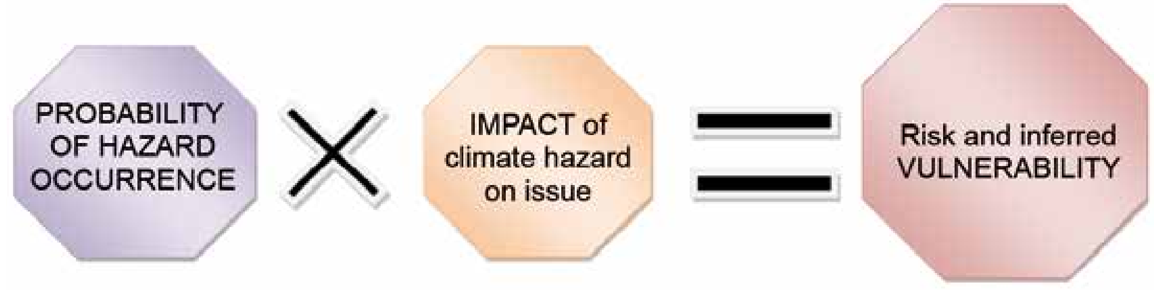
IMPACTS ON OPERATIONS

- problems of visibility caused by smoke from forest fires in the event of droughts and heat waves;
- inoperable runways due to more frequent, stronger crosswinds;
- temporary runway closures due to FODs (Foreign Object on Debri) after storms or high winds;
- airport closures due to cyclones, storm alerts or after a storm or cyclone, isolation of territories (including French overseas territories);
- fewer air traffic interruptions and/or delays due to bad winter weather conditions;
- more difficult working conditions on aprons, leading to absenteeism;
- temporary closures of runways or taxiways due to flooding after periods of heavy rain;
- different bird species and wider distribution areas, more birds in the vicinity of the airport thereby increasing the risk of avian accidents.

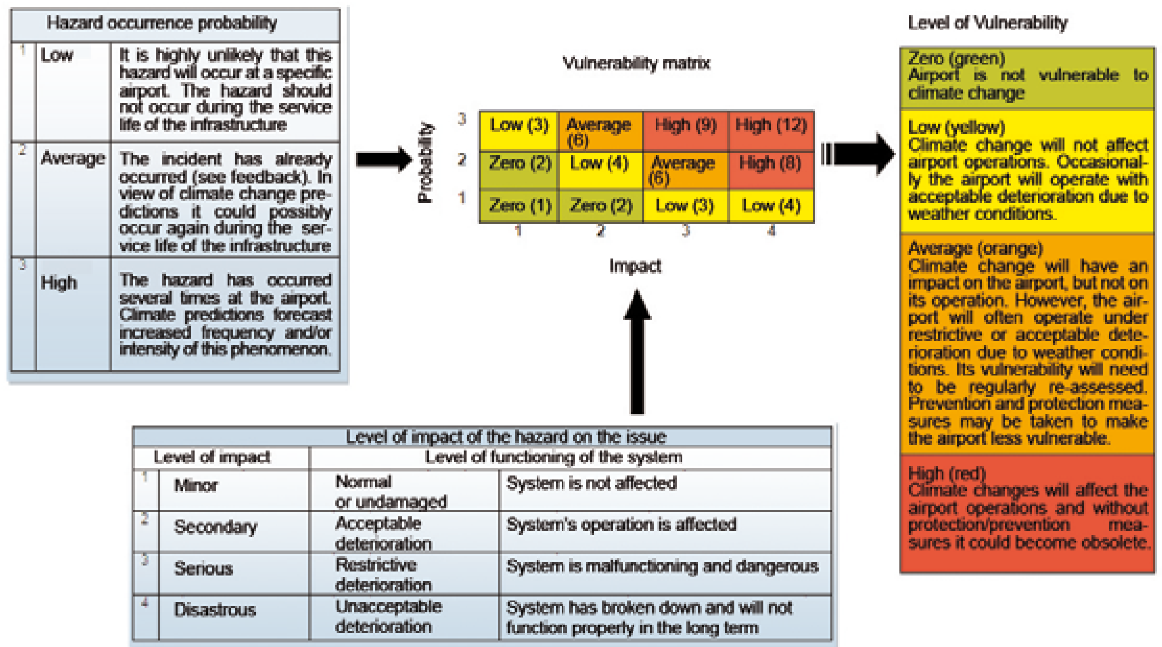
VUCLIM: A METHOD TO DIAGNOSE AN AIRPORT'S EXPOSURE TO CLIMATE CHANGE

METHODOLOGY

The proposed method maps risks. Its main advantage is that it summarises each stage of a vulnerability analysis and thus provides a readable accessible end result. First, the approach consists of doing a detailed analysis of the airport (or of the problem) to obtain detailed information on the «transport» aspect (the issue, vulnerability to known malfunctions such as breakdowns, which are prerequisites to solve the issue, and second, define climate change scenarios in which a climate hazard is clearly identified and a specific scenario is clarified. Analysis of future climate vulnerability is complex because we need to grasp a situation that does not yet exist. This type of analysis predicts the climatic aspects of the territory (average and extreme characteristics). Analysing past events and feedback are an important part of the approach, especially in grasping extreme weather events, and is indispensable for vulnerability analysis. Comparing the two analyses (airport and climatic hazard issues) make it possible to look at it from two angles: the probability of a hazard occurring versus the level of impact of the climate hazard on the issue; the output is the actual risk.



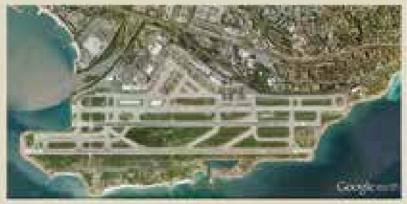
Assessment of vulnerability resembles a two-way table including on the one hand, the climate hazards that are likely to have an impact on the airport, and on the other, the different aspects of the issues faced by the airport



APPLYING THE METHODOLOGY TO NICE COTE D'AZUR AIRPORT

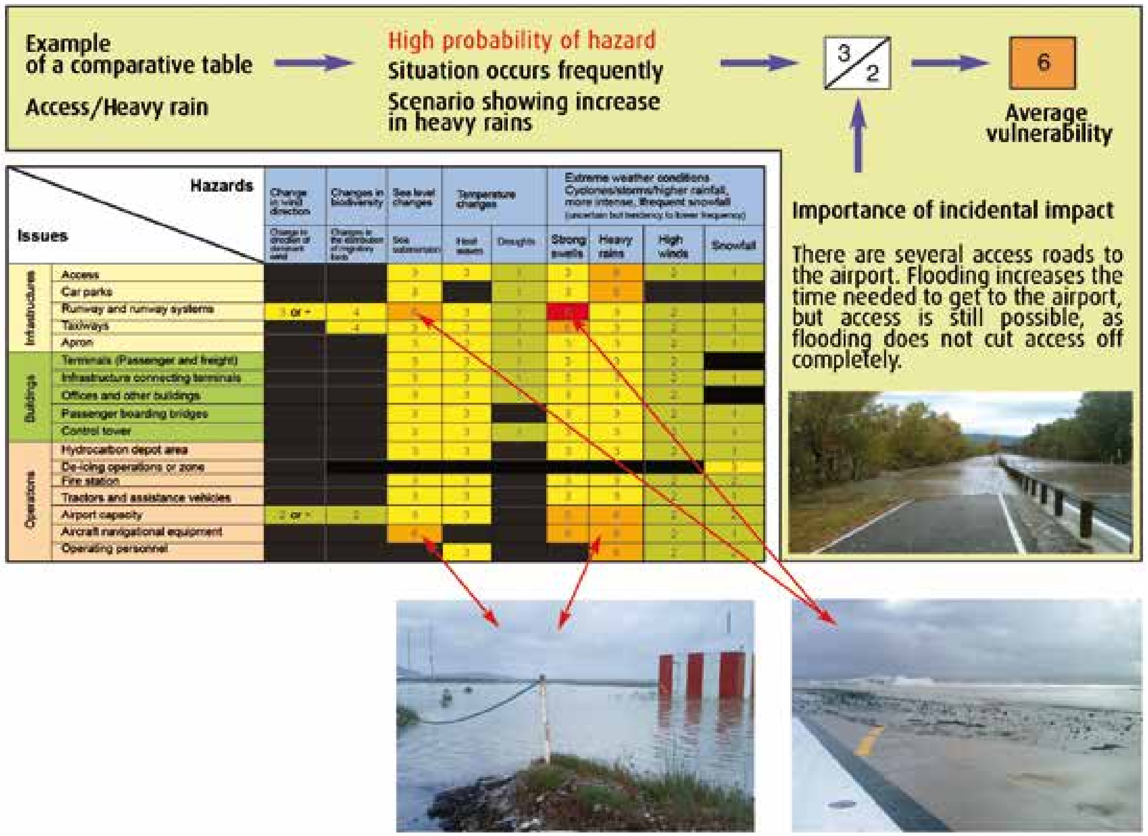
CHARACTERISTICS:

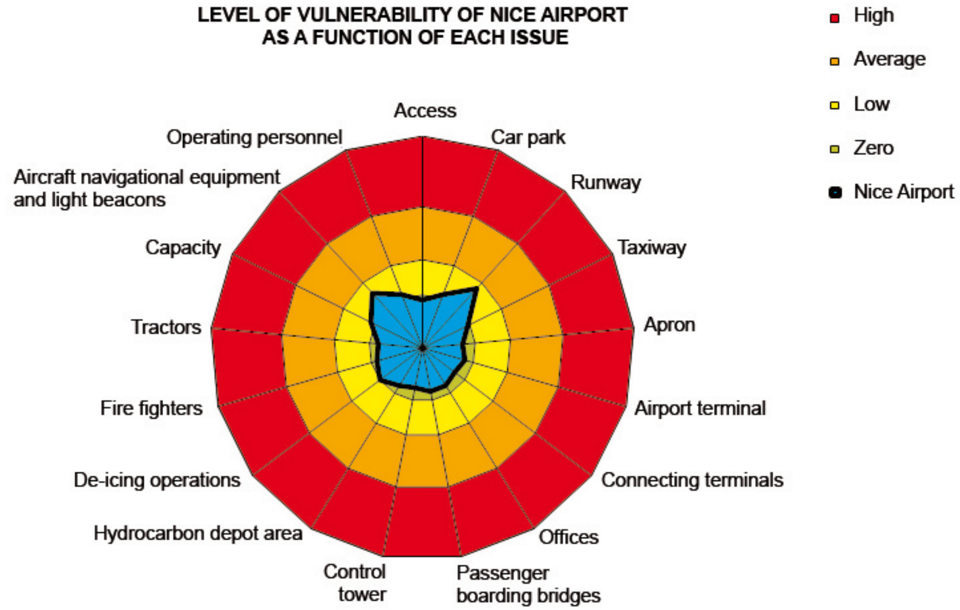
- Nice is the third biggest airport in France with over 11 million passengers in 2012 a total of 176,400 take offs and landings;
- it covers a surface area of 370 ha, of which 200 ha are built in the sea;
- two runways;
- two terminals;
- in 2010, 21% of flights were cancelled due to bad weather conditions.

Name	Nice Côte-d'Azur
Code OACI/IATA	LFMN/NCE
Map	Aerial view
	

Nice Côte d'Azur Airport's vulnerability grid, which was filled in in collaboration with the operator, reveals its strengths (yellow and green zones) and weaknesses (orange and red zones) in the face of climate change.

Some sea swells disrupt airport operations by depositing stones on the runways, flooding some of the manoeuvring areas or preventing the evacuation of runoff. The vulnerability of the airport to these phenomena will increase with the predicted rise in sea level.





NICE COTE D'AZUR VULNERABILITY DIAGNOSTIC MAPPING

The projection of a vulnerability grid represents the degree of vulnerability, here in blue. An airport's vulnerability is high if the blue area is predominant. Most of Nice Airport's components are in the zero or low vulnerability zone. Vulnerability is higher on two issues, the runway system and aircraft navigation equipment, and light beacons. In fact, if one refers to the vulnerability matrix, the vulnerability of the runway system and aircraft navigation equipment and light beacons is average (orange) , the vulnerability of the «runway» is high (red).

PREVENTION DIAGNOSIS

As Nice Airport's runway system is partly built on the sea and is low-lying, it will be vulnerable to overtopping in strong swells and this phenomenon will be more frequent due to the rise in sea level. «Côte d'Azur Airports» has conducted maintenance of the existing sea dyke. Works to reinforce the riprap protecting the runways from overtopping on the airport's seafront side, particularly runway entrances and exits were undertaken between 2011 and 2013 for a total cost of 10.4 million Euros.

REFERENCES

- www.circeproject.eu European research project on climate change;
- http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012, European Environment Agency website, page dedicated to climate change;
- http://onerc.org/ National Observatory on the Effects of Global Warming;
- www.developpement-durable.gouv.fr/Scenarios-regionalises-janvier NAPCC validated climate scenarios (in French);
- www.developpement-durable.gouv.fr/IMG/pdf/UCC-ONERC-complet.pdf NAPCC related website (in French).
- www.drias-climat.fr a website that aims to give regionalised (France) climate projections;
- -www.prim.net Ministry for major risks website (in French);
- http://www.cnrm-game.fr/spip.php?article531 National Weather Research Center, World Meteorological Organisation studies;
- http://infoterre.brgm.fr and www.argiles.fr identify geographical areas subject to low, medium or high risk of clay shrinkage/swelling phenomenon http://infoterre.brgm.fr;
- http://imfrex.mediasfrance.org extreme phenomena, wind and rainfall (in French);
- Site http://imfrex.mediasfrance.org/web gives information on the frequency of wind, temperature and rainfall extreme phenomena due to the impacts of anthropogenic changes;
- http://pluiesextremes.meteo.fr site dedicated to «extreme rainfall» which aims to advise on the frequency of such events and presents the most important ones in France, from 1958 to 2009 (in French);
- http://flood.firetree.net rising water simulator, developed by Google.

3.3 / VULNERABILITY OF AIRPORTS IN FRENCH OVERSEAS TERRITORIES TO CLIMATE CHANGE

Most airports in overseas territory are located on the coastal strip and are thus at very low altitude; generally these structures are exposed and vulnerable.

The following airport infrastructure should be considered as sensitive:

- roadways: rapidly wear, weakening road structures and soil foundations that are more sensitive to water (particularly clay) when in contact with groundwater tables, which can may necessitate the review of PCN;
- any building superficially built on soils that are sensitive to variations in moisture is likely to develop large or small cracks;
- runway flooding: total submersion and/or rising waters blocking sewage outlets, rendering the situation described in the previous sentence even worse;
- light beacons and electric navigation assistance systems can be disrupted by rising waters and rainfall;
- terminals and other buildings whose floor levels are liable to flooding, submersion, especially operational buildings essential to aircraft movement, including FOD (Foreign Object Damage);
- runways and airstrips likely to be covered with marine and other debris;
- runways and airstrips likely to be partly damaged by landslides;
- airstrips' riprap protections;
- aboveground equipment exposed to violent winds;
- runways may remain unusable for quite a long time following a catastrophic situation requiring emergency relief services (on site storage);
- under average climate changes, short runways will require altering: if the average temperature increases substantially, aircraft weight and the operating conditions will need changing (i.e. the aircraft's take-off weight), or a runway extension will be required, otherwise plan PORs;
- air conditioning in technical buildings housing sensitive electronic equipment (control systems) will need to be reinforced, possibly also in buildings that are open to the public;

- runway orientation: if the prevailing wind, which originally determined the orientation of the runway, permanently changes direction, the runway will have to be closed beyond a certain limit due to the many QFR risks. Rebuilding could be considered, but often at another site (the case in narrow atolls);
- light weight, fragile components (especially in aircraft accidents), mobile units, roofs etc., and airplanes (untimely departures) subject to violent winds;
- airport visibility: average visibility, difficult in cloudy weather;
- interrupted service during low depressions or cyclone alerts: airports may be closed as a precaution during these weather conditions and afterwards for repairs.

3.4 / CONSTRUCTION OF MAJOR PORTS IN OVERSEAS TERRITORIES

Since 1st January 2013, France has four new major ports in overseas territories. This was the result of five law enforcement decrees on the reform of ports in French overseas territories under the February 22, 2012 Law, published on October 2, 2012.

The new public ports replace Guadeloupe's autonomous port, and three ports of national interest run by the local Chambers of Commerce and Industry in Fort-de-France (Martinique), Degrad-des-Cannes (French Guyana) and Le Port-Reunion (Reunion Island).

APPENDIX 4

4.1 / MEANING OF FRENCH AND INTERNATIONAL ABBREVIATIONS AND ACRONYMS

- **ADEME:** Agency for Environment and Energy Management.
- **AEP:** Drinking water supply.
- **AFD:** French Development Agency.
- **ANC:** Non-Collective Sewerage system.
- **ARDA:** Reunion Island Association for the Development of Aquaculture .
- **CC:** Climate Change.
- **CETMEF:** Centre for Marine and Fluvial Technical Studies.
- **DGAC** : French Directorate General for Civil Aviation.
- **DIG:** Declaration of General Interest – An operation is declared of public interest by prefectural decree after a public inquiry. This declaration enables the use public funds for a recognised problem of general interest in the private domain.
- **EEZ:** Exclusive Economic Zone.
- **FAD:** Fish Aggregating Devices.
- **FAO:** Food and Agriculture Organization of the United Nations
- **FRMP:** Flood Risk Management Plan.
- **HWIP:** Household Waste Incineration Plants.
- **IATA:** International Air Transport Association.
- **ICAO:** International Civil Aviation Organization – an international organisation under the United Nations' authority. Its role is to participate in developing international aviation transport standards.
- **ICPE:** Facilities subject to Environmental Protection Statutes- List of facilities subject to an authorisation or declaration by decree whose exploitation presents severe hazards or could inconvenience the neighbourhood, or health, safety, public safety, agriculture, the protection of nature and environment or the conservation of sites and monuments (Act 76-663 of 19/07/76).
- **IEDOM:** Central Bank for French Overseas territories. IEDOM ensures territorial monetary continuity, delegated by France's Central Bank, in five of its Overseas departments.
- **IEOM:** Central Bank for French Overseas Countries - It is the Central Bank for French Pacific Overseas communities (New Caledonia, French Polynesia, Wallis and Futuna).
- **IFRECOR:** French Initiative for Coral Reefs. Founded in 1999, to protect and sustainably manage coral reefs and related ecosystems (mangroves, seagrass meadows) in French overseas territories and collectivities; it is made up of a national panel and a network of 8 local committees representing French authorities

that have coral reefs: Guadeloupe, Martinique, Reunion, Mayotte, Eparses islands, New Caledonia, Wallis and Futuna and French Polynesia.

- **IFREMER:** French Research Institute for Exploitation of the Sea.
- **IPCC**: Intergovernment Panel on Climate Change.
- **IUCN:** International Union for the Conservation of Nature.
- **LPRP:** Coastal Risk Prevention Plan 1997.
  - Taking into account the risk of sea submersion, the methodological framework dates from 1997, and should be updated and incorporate climate change;
  - Marine Strategy Framework Directive (MSFD);
  - Integrated Coastal Zone Management (ICZM);
  - Coastal planning Schemes (SMVM);
  - Coastal Regional development plans (SAR) and Sustainable development and planning plans (PADD).
- **LUP:** Local Urban Planning – a communal planning document drafted by the Urban Solidarity and Renewal (USR) law of 13th December 2000. It replaces the Land Use Plan and sets out land use rules. It can also contain operational planning projects such as existing neighbourhood amenities or new public spaces or a town's access roads, etc. The USR law is Law No. 2000-1208 of 13th December 2000 for urban solidarity and renewal.
- **MDP:** Maritime Public Domain.
- **MEDDE:** Ministry of Ecology, Energy and Sustainable Development.
- **MRE:** Marine renewable energies.
- **NAPCC:** National Adaptation Plan to Climate Change.
- **ONERC:** French National Observatory of the Effects of Climate Change.
- **PE:** Population equivalent is a unit of measure defined as the organic biodegradable load requiring biological application oxygen in five days (BOD5) 60 grams of oxygen per day. It makes it to easy to define the size of treatment plants based on the polluting load.
- **Polmar Plan:** Rapidly neutralises an oil spill in a port or at sea.
- **POS:** Land Use Plan.
- **PPNR:** Plans for the Prevention of Natural Risks.
- **RCP:** Representative Concentration Pathways - To improve our responsiveness, the Scientific community has defined four representative profiles of changes in greenhouse gas concentrations.
- **RDP:** Rural Development Programme.
- **RPP:** Risk Prevention Plan.
- **RSP:** Rapid submersion plans.
- **SCOT:** Territorial Coherence Scheme – a strategic urban planning document, for several municipalities or groups of municipalities, which sets out the fundamental organisation of the territory and changes in urban areas in order to preserve a balance between urban and industrial areas, tourism, agricultural and nature areas. Established by the Solidarity and Urban Renewal Act of December 13, 2000, it sets goals for various public housing policies, economic development, and urban mobility.
- **SDAL:** Master Plan for Coastal Management.
- **SDAU:** Urban Development Plan.
- **SRDAM:** Guyana's Regional Marine Aquaculture Development Plan.
- **SRES:** Special Report on Emission Scenarios - Scenarios produced by the IPCC.
- **SS:** Suspended solids.
- **SWAC:** Sea Water Air Conditioning, cooling process using the ocean's deep cold water.
- **TAAF:** Southern and Antarctic French territories.
- **TAC:** Combustion turbines.
- **TCAS:** Technical Civil Aviation Service.
- **TME:** Thermal marine energy.
- **UAA:** Useful agricultural area.
- **WMO:** World Meteorological Organisation, United Nations' authority on weather, climate and water.
- **WWTP:** Wastewater treatment plants.

4.2 / LIST OF TABLES

4.3 / GLOSSARY

HYDROLOGY AND HYDROGEOLOGY

- **Alluvial deposits:** River and lake sediment consisting of small stones, gravel and sand often origination from lenticular deposits that vary depending on the regions they cross and on the strength of the current. The fine layers are clays and silts.

- **Alterite:** Superficial formation resulting from on-site alteration and fragmentation of the rock base without noticeable transformation of the soil.

- **Aquifer:** Permeable rock layer which allows a significant flow of groundwater and captures large quantities of water. An aquifer has a saturated zone, but may also have an unsaturated zone.

- **Aquifer capacity:** gravitating water from an aquifer, depending on its total volume (average or maximum) of saturated rock and its storage coefficient. It describes the functional capacity of an aquifer system. A capacitive aquifer when it can take a significant amount.

- **Aquifer Capture:** capturing the aquifer for water supply and whatever other use.

- **Artesian:** In broad terms, this refers to a well or borehole in which the water rises higher than its source level, or to wells in which water emerges at the surface. In both cases, wells or boreholes use a captive water table.

- **Basin network:** This network compriuses government departments and agencies which provide or gather information on water and aquatic environments, at the scale of a catchment.

- **Basket strainer:** Perforated tube placed at the bottom of a borehole, at the level of the aquifer. It acts as a filter by letting the water drain into the structure whilst giving support to the surrounding area.

- **Body of Water:** A water boy is a stretch of water, a lake, pond, section of coastal waters, that is part or all of one or several aquifers that are large enough to allow biological and physical-chemical processes to occur. It is homogeneous both in terms of quality and quantity, justifying specific management. It is the method of analysis used to implement WFD.

- **Borehole:** A well dug by a mechanical process (drill) in ground that is consolidated (or not), for all purposes, except for reconnaissance or observation structures , which is known as sounding.

- **Captive water table:** Part of or a water table with no open surface area, thus subject to greater pressure than atmospheric pressure and whose piezometric surface is larger than the top cover of the aquifer.

- **Clay:** A mineral or rock consisting essentially of clay minerals. They are characterized by the small particle size, less than 3.9 um.

- **Evapotranspiration:** The emission of water vapour which results in two phenomena: evaporation, which is purely physical, and plant transpiration.

- **Flow:** Volume of water flowing through a river cross-section per time unit.

- **Hydrographical basin:** Generally refers to a large catchment area. An area where all runoffs converge through a network of streams, rivers and, possibly lakes and flows into the sea via a single river mouth, estuary or delta.

- **Hydrometric stations:** A hydrometric station is a structure built on a watercourse or a water reservoir in order to measure its flow continuously.

- **Inter-Service Organisation for Water (French acronym MISE):** A departmental coordination structure for French State services (DDASS, DDAF, DDE, etc.) that aims to improve the legibility, effectiveness and coherence of administrative actions, primarily in policing water in terms of managing water and aquatic environments.

- **Karstification:** Process of dissolution of limestone by carbon dioxide charged meteoric waters.

- **Local Water Commission (CLE):** A Consultation Committee set up under the Water Law and established by the city Commissioner, it is responsible for developing, reviewing and monitoring a water development and management plan (SAGE). Its composition is fixed by law and specified by a decree (half are elected representatives, one quarter are user representatives, and one quarter are State representatives). The president must be a member of the elected representatives and is elected by them.

- **Master Plan for the Development and Management of Water (French acronym SDAGE):** This is a scheme for each large basin area. It was established by the 1992 Water Act.

- **Matrix (silty or sandy):** The encompassing part of a rock made up of large elements, which can also be composed of smaller components or an undifferentiated mass.

- **Outfall :** A place where water comes out of or can come out of an aquifer.

- **Particle sizing:** Study of the particle distribution of rocks according to size. The size categories are then defined based on a minimum and maximum diameter.

- **Permeability:** An environment's ability to allow a fluid (liquid or gas) to pass through it, typical of sandy or gritty land and cracked and karstic environments.

- **Piezometer:** A device to measure fluid pressure. In hydrology, this instrument is used to measure the height of a water table at a given point in an aquifer system, indicating the pressure at the point concerned. It indicates the level of free water or pressure.

- **Piezometric level:** Water level measured in a borehole by a piezometer. It characterises the pressure of the water table at a given point. It is measured against the mean sea level (0 MSL).

- **Plot survey:** Survey to identify plots to be expropriated and their real estate rights. It gives rise to transferability by the city Commissioner.

- **Porosity (interstitial porosity aquifers):** Porosity or the void fraction is a measure of the spaces, interconnected or not, in a material or environment, and is a fraction of the volume of voids over the total volume. An aquifer in a porous environment is characterised by a set of sedimentary materials like gravel, sand, silt, incorporating an area saturated in water allowing water to pass or a water table to flow through the pores and capturing significant quantities of water for different uses. This type of aquifer is found in alluvial areas and coastal plains where sediments have accumulated over geological time.

- **Public Utility obligations:** Administrative obligations annexed to the Local urban planning in Article L. 126-1 of the Town Planning Code. A public utility obligation is the public's safety and security; a heritage protection can be added to it, as can the use of certain resources and equipment, and national defence.

- **Recharge:** Natural increase in hydraulic load: the difference in pressure due to a rise in the water table within a specific timeframe.

- **Saltwater intrusion:** Part of a coastal aquifer invaded by saltwater from the aquifer's base and a fresh/saltwater interface. This saltwater intrusion is usually the consequence of an overexploited aquifer.

- **Stage graph:** Graphical representation of variations in the surveyed water level at a given point (wells, piezometer), registered by a limnigraph or based on successive instantaneous readings.

- **Sub-watersheds:** Areas in which all runoff converges, through a series of streams, rivers and possibly lakes to a specific water body (normally a lake or a confluence).

- **Water Development and Managing Scheme (SAGE):** This scheme is a tool for a local water planning policies to ensure a coherent hydrographical unit. It was established by the 1992 Water Act.

- **Water Distribution Zones (ZRE):** Defined under the April 29, 1994 Decree, these are areas where there are insufficient resources compared to needs, excluding exceptional circumstances; the decree aims to reconcile the interests of different water users; the authorisation and declaration of nomenclature thresholds therein are binding.

- **Water Framework Directive (WFD):** The Water Framework Directive is the European directive that establishes a framework for Community action in the water domain (Directive 2000/60/EC of the European Council of 23rd October 2000). It was transposed into French law under Law No. 2004-338 of April 21, 2004.

- **Watershed:** A land area supplying rivers or lakes, similar to an outlet, where surface water drains off or comes from under the surface and flows into one place.

- **Well:** Any excavation dug from the surface of the ground

AIRPORT

- **CHEA:** Procedures required for airport operational approval regulations;

- **Commercial Aviation:** Commercial transport of passengers or cargo on regular routes. The term «General Aviation» is used for all other flights;

- **Cyclone, low depression, hurricane:**

  Global terminology:

  In the French Antilles, the term cyclone was used for violent cyclones that reached the hurricane stage. It was important to harmonise terminology used throughout the region, Miami's Specialised Centre is the authority on the matter. Since 1986, the term «hurricane» is used to describe cyclones with intense winds.

  However, the Creole language continues to use the word «siclon» so the terms cyclone and hurricane are sometimes confusing. However, meteorologists identify the phenomenon using its different intensities (tropical depression, tropical storm, hurricane).

  In the Indian Ocean, we talk about tropical depressions, storms (moderate or strong according to the wind's strength) and cyclones, the latter can be distinguished by the difference in intensity between intense and very intense.

  In the Western Pacific (China Seas, Japan, including Philippines and surrounding area), the term «typhoon» is used, if it is very intense (super-typhoon) or not.

  The Eastern Pacific (off Central America and around Hawaii) area is administered by the Miami Hurricane Centre which uses the same terminology as in the Antilles and the USA - © 2010 Meteo France.

  http://webissimo.developpement-durable.gouv.fr/IMG/pdf/C_1101_cle2a11a2.pdf

- **GLIDE:** Critical area of an aircraft's landing descent course;

- **Helipad:** A helipad is a helicopter landing area. This type of platform does not provide heliport services such as fuel supplies or weather services, nor air traffic control;

- **Hydrant system:** A pipe network which supplies fuel from the airport's storage facilities to the tarmac;

- **IATA:** International Air Transportation Association, a trade association for all the world's airlines;

- **ICAO:** International Civil Aviation Organization is under the authority of the United Nations. Its role is to participate in developing international aviation transport standards;

- **ILS:** Instrument landing system, which includes the landing course transmitter, the «localiser» and descent course the «Glide path», and distance information;

- **PAPI:** Set of 4 red lights (2 for «APAPI») which check the correct final altitude approach;

- **Runway clearance zones:** Zones to reduce the risks of damage to aircraft if they come off the runway, part of its surface is levelled in case they accidentally need to use it;

- **Runway unobstructed zones:** These zones must remain free of obstacles, they surround the clearance zones and are part of the obstacle limitation surfaces «OLS» or aeronautical clearance surfaces;

4.4 / MINISTRIES AND DEPARTMENTS

MINISTRIES

- Ministry of Ecology, Energy and Sustainable Development: www.developpementdurable.gouv.fr/
- State Secretariat for Transport, Sea and Fisheries, attached to the Minister of Ecology, Energy and Sustainable Development: http://www.developpementdurable.gouv.fr/Transports,1310-.html
- Ministry of French Overseas territories: http: // www.Outremer.gouv.fr/

DEPARTMENTS WITH NATIONAL JURISDICTION

- Center for tunnel studies (CETu): www. cetu.developpement-durable.gouv.fr/
- Center for engineering and IT services (CP2i): http://lannuaire.servicepublic.en/services_nationaux/service-a-competence-national_185900.html
- DGAC information systems and modernisation department: http: // lannuaire. service-public.fr/services_nationaux/service-a-competence-nationale_430478.html
- Department for Human Resources Development (CMVRH): http://www.developpement-durable.gouv.fr/
- National Centre for Emergency Bridges (CNPS): www.cnps.developpement-durable.gouv.fr/
- Civil Aviation Safety (DSAC): http: //www.developpement-durable.gouv.fr/-Directions-de-la-Securite-de-l-.html
- Air Navigation Services (DSNA): http: //www.developpementdurable.gouv.fr/-Navigation-aerienne-.html
- Airport tax service (SGTA): http://lannuaire.service-public.fr/services_nationaux/service-a-competence-nationale_432489.html
- National airport engineering services (SNIA): http: //www.rst.developpementdurable.gouv.fr/snia-r75.html
- Technical Civil aviation Service (TCAS): www.stac.aviation-civile.gouv.fr/
- Electrical energy and large dams technical service (STEEGB): http: //lannuaire.service-public.fr/services_nationaux/Service-a-competence-nationale_179159.html
- Environmental Training Institute (IFORE): www.ifore.developpement-durable.gouv.fr/

Since 1st January 2014, the French organisations CERTU, CETMEF, SETRA and the 8 CETE are grouped together in a new public institution called CEREMA (Centre for Studies and Expertise on Risks, Environment, Mobility and Development).

In French overseas territories, this service is called DEAL (Regional Department for Environment, Planning and Housing) and has only existed since 1st January 2011.

INTER-REGIONAL AND INTER-DEPARMENTAL DEPARTMENTS

- 4 Inter-regional directorates for the sea (DIRM) in mainland France and 4 in regional overseas territories
- 11 Inter-departmental directorates of roads (DIR).

The inter-departmental directorates, particularly for territories and the sea also work under their respective ministries.

This is also the case of the Directorate of Equipment (DE) for communities in French overseas territories.

MEDDE is a unique or shared directorate of the following public institutions:

- French Marine Protected Areas Agency (AMPA): www.aires-marines.fr/
- Agency for Environment and Energy Management (ADEME): www.ademe.fr/
- Agency for Food, Environmental and Occupational Health Safety (ANSES, which has replaced AFSSET, formerly AFSSE): https://www.anses.fr/
- National Housing Agency (ANAH): www.anah.fr/
- National Agency for Radioactive Waste Management (ANDRA): www.andra.fr/
- Geology and Mining Research Institute (BRGM): www.brgm.fr/
- Centre for Studies and expertise on Risks, the Environment and Urban Mobility (CEREMA): www.cerema.fr/
- Scientific Centre and Technical Building (CSTB): www.cstb.fr/
- Coastal Conservatory (CELRL): www.conservatoire-du-littoral.fr/
- Commission for Atomic and alternative energy (CEA2): www.cea.fr/
- French Research Institute for the Exploitation of the Sea (IFREMER): www.ifremer.fr/
- IFP New energies: www.ifpenergiesnouvelles.fr/
- National Institute of Geographic Information and Forestry (IGN): www.ign.fr/
- National Institute for Industrial Environment and Risks (INERIS): www.ineris.fr/
- French Institute of Science and Technology, transport, development and networks (IFSTTAR): www.ifsttar.fr/
- National Road Safety and Research Institute (INSERR): www.inserr.org/
- Institute for Radiological Protection and Nuclear Safety (SNRIs): www.irsn.fr/
- Meteo-France: www.meteofrance.com/
- National Agency for Water and Aquatic environments (ONEMA): www.onema.fr/
- National Forestry Office (ONF): www.onf.fr/
- National Hunting and Wildlife Office (ONCFS): www.oncfs.gouv.fr/
- The seven major seaports
- The five autonomous ports: two in mainland France, and three in the overseas territories
- Some urban planning agencies
- Some public land institutions (EPF)
- Some public planning development institutions (EPA)

TEXTS

- Decree No. 2008-680 of 9th July 2008 on the structure and function of the Ministry of Ecology, Energy, Sustainable Development and Spatial Planning;
- Decree No. 2012-772 of 24th May 2012 on the responsibilities of the Minister of Ecology, Energy and Sustainable Development's powers;
- Decree No. 2012-805 of June 9th, 2012 on the Minister's authority to the Ministry of Ecology, Energy and Sustainable Development, in charge of maritime transport and economy.

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FOR MORE INFORMATION

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- SIRECCO website (IFRECOR's website with resources on Climate change and Overseas territories): http://portail-scientifique.univ-nc.nc
- ONERC website (French National Observatory for the effects of climate change): http://www.developpement-durable.gouv.fr/-Impacts-et-adaptation-ONERC-.html
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Fish and coral reef, Guadeloupe. Photo: © Franck Mazéas

THE IMPACT OF CLIMATE CHANGE ON INFRASTRUCTURE IN COASTAL AND INTER-TROPICAL MARINE ZONES